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THE ASSOCIATION was organized in Boston, Mass., on June 21, 1882, with the object of providing its members with means of social intercourse and for the exchange of knowledge pertaining to the construction and management of water works. From an original membership of only TWENTY-SEVEN, its growth has prospered until now it includes the names of 800 men. Its membership is divided into six classes, viz.:

A Member shall be an officer or employee of a public or private water works, an engineer, chemist or other person qualified to aid or interested in the advancement of knowledge relative to water works.

An Honorary Member shall be a person of acknowledged eminence in some branch of water supply or of engineering.

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An Associate shall be either a person, firm or corporation engaged in manufacturing or furnishing materials or supplies for the construction or maintenance of water works.

A Corporate Member shall be either a Water Board, Commission. Company or Municipal Corporation.

The initiation fees and annual dues are as follows:

Initiation Fees		*Annual Dues*	
Members	$ 3.00	Members	$ 6.00
Juniors	1.00	Juniors	3.00
Associates	10.00	Associates	20.00
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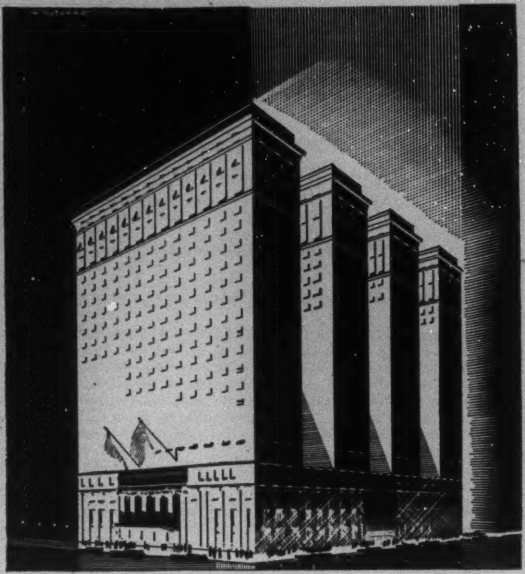

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Official Convention Headquarters

for the

NEW ENGLAND WATER WORKS
ASSOCIATION

1936 CONVENTION

Our fifty-fifth annual convention will be held this year at the Hotel Pennsylvania in New York City from September 22 to 25 inclusive.

A stimulating technical program is being prepared which includes two symposiums—one on the 1936 floods, and the other on water purification—; papers descriptive of the New York City and Dayton, Ohio water supplies; a guest speaker from England; a Superintendents' Session; a Superintendents' Round Table; and other features.

The entertainment committee is making elaborate plans with facilities that only the great city of New York can offer.

Plan now to attend this educational holiday, and meet your colleagues from all over the country.

Table of Contents

PAGE
The New Water Treatment Plant of the Salem and Beverly Water Supply Board. By Frank A. Marston and John W. Raymond 111
Water Department Regulation of Water Pipes Within Buildings. By Stephen H. Taylor 129
Ten Years of Sanitary Improvements in Rhode Island Public Water Supplies. By Charles L. Pool and James J. Dillon 143
Public Ground Water Supplies in Massachusetts. By Francis H. Kingsbury 149
The Water Supply of a State Institution. By Bayard F. Snow .. 197
Procedure in Developing a Ground Water Supply by Driven Wells. By Ralph W. Horne 207
Determining the Yield and Quality of Tubular Wells by Means of the Well Rater and Sampler. By Paul F. Howard 219
Geologic Features in New England Ground Water Supply. By Kirk Bryan 222
Occurrence of Iron in Ground Water and Early Experiments upon Removal. By Harry W. Clarke 229
Some Problems of Deferrization and Demanaganization. By Robert Spurr Weston 231

Proceedings.

February Meeting 239
March Meeting 241
Spring Meeting, Hartford, Conn. 242
Spring Meeting, Concord, N. H. 243

Obituaries.

Xanthus Henry Goodnough 244
Fayette F. Forbes 247

New England Water Works Association
ORGANIZED 1882.

Vol. L. June, 1936. No. 2

This Association, as a body, is not responsible for the statements or opinions of any of its members

THE NEW WATER TREATMENT PLANT OF THE SALEM AND BEVERLY WATER SUPPLY BOARD.

BY FRANK A. MARSTON* AND JOHN W. RAYMOND, JR.†

[*Read September 18, 1935.*]

The water supply of the cities of Salem and Beverly, Mass., is obtained from the runoff of the watersheds of Wenham Lake and Longham Reservoir and from water diverted from Ipswich River into Wenham Lake. The quality of the water thus obtained has been the source of criticism for some years, particularly with respect to physical characteristics, but also at times with reference to bacterial content. To remedy these conditions a plant has been built to treat the water by chemicals and by filtration through rapid sand-filters. This plant has been built as an ERA project, and is said to be one of the largest of such projects in the United States involving complicated construction work.

Sources of Water Supply. The city of Salem was authorized to take water from Wenham Lake by Acts of 1864 and the city of Beverly by Acts of 1885. This lake, having an effective drainage area of about 3.5 sq. mi. and a surface area when full of 250 acres, is situated partly in the town of Wenham and partly in Beverly. (See Fig. 1.) The lake has a storage capacity of 1 950 m.g. of which 800 m.g. are available above the lowest level to which it is desirable to draw the water. Experience has shown that objectionable odors have been the subject of complaint when the lake has been drawn down more than 12 ft.

Longham Reservoir was built in 1895 under authority of Acts of 1893. It is situated in Wenham close to the Beverly line, has a drainage area of 3.28 sq. mi. and a surface area when full, of 43 acres. The capacity is 55 m.g. Water from this reservoir flows by gravity through a 36-in. cast-iron pipe to Wenham Lake, for which a head of 5 ft. is available when both the reservoir and the lake are full.

The diversion of Ipswich River water for Salem and Beverly was authorized by Acts of 1913 and is limited to the excess of flow in the river over 20 m.g.d. and to a total diversion in any year of not over 2 500 m.g., which according to the Act must be taken between December 1 and May 31.

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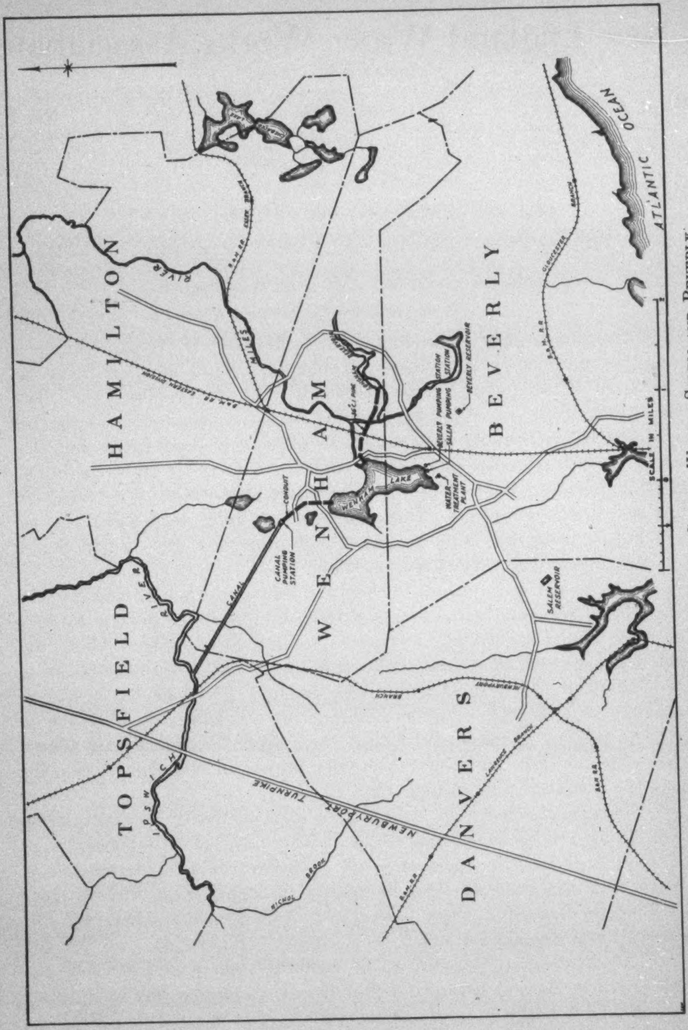
*Partner, Metcalf & Eddy, Engineers, Boston, Mass. †Resident engineer.


HAMILTON
TOPSFIELD
WENHAM
BEVERLY
DANVERS
ATLANTIC OCEAN
IPSWICH RIVER
RIVER
MILES
CANAL
CANAL PUMPING STATION
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WENHAM LAKE
WATER TREATMENT PLANT
BEVERLY PUMPING STATION
SALEM PUMPING STATION
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SALEM RESERVOIR
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NEWBURYPORT BRANCH
LAWRENCE BRANCH
ESSEX BRANCH
B. & M. R.R. EASTERN DIVISION
SCALE IN MILES
0
1
2

FIG. 1.—LOCATION OF WATER SUPPLY WORKS, SALEM AND BEVERLY.

Later Acts have changed this last restriction so that, with the approval of the State Department of Public Health, water may be taken also during the months of June to November, if necessary.

For a dry year like 1914, these sources of supply are estimated to have a dependable yield of 6.9 m.g.d.

Authority. Since 1913, the water supply works have been operated by the Salem and Beverly Water Supply Board, now consisting of the City Engineer of Salem, Frank P. Morse, the Commissioner of Public Works of Beverly, James W. Blackmer and the Chairman, appointed by the Governor for a three-year term, Charles Ross, Esq., of Boston. Funds for operating the works and for building new works, except as provided in the latter case by the Federal Government, are obtained two-thirds from the city of Salem and one-third from the city of Beverly. The Board is concerned only with the supply works and has no responsibility or authority with respect to the distribution of water, a function retained by the cities.

Water Consumption. Salem is an industrial community, whereas Beverly is residential in character. The effect of the installation of service

TABLE 1.—WATER CONSUMPTION OF THE CITIES OF SALEM AND BEVERLY.

Year.	Salem.		Beverly.	
	Annual average water consumption g.p.d. per capita.	Per cent. metered services.	Annual average water consumption g.p.d. per capita.	Per cent. metered services.
1912	000	000	91	15
1913	000	000	90.9	23
1914	000	000	86.7	24
1915	000	000	69.9	23
1916	000	000	67.9	24
1917	000	000	66.7	30
1918	000	000	75.0	35
1919	130	4	56.0	47
1920	134	5	70	51.4
1921	129	6	66.9	59.3
1922	115	7	59.4	63.1
1923	116	9	65.2	70
1924	116	11.6	58.9	72.5
1925	128	14.9	62.8	78.2
1926	126	22.7	63.9	79.5
1927	107	35	61.9	85
1928	115	42	60.5	88
1929	117	53.8	66.3	90
1930	116	65.1	60.0	91
1931	112	77.8	58.7	92
1932	98	80.5	59.9	92
1933	97	82.9	58.1	92
1934	114.6	82.9	64.9	92
1935	100	83	63	92

meters in reducing unnecessary waste of water is well illustrated by the statistics from these cities. The marked reduction in water consumption in 1932 and 1933 was due to the business depression.

Table 1 shows the annual average per capita use of water and the per cent. of services metered in each city, since the installation of meters has been an active program.

For the year 1934, the annual average water consumption in Salem was 4.97 m.g.d. and for Beverly 1.63 m.g.d., a total of 6.60 m.g.d. For the maximum month, July, the average was 7.67 m.g.d. On the day of maximum demand in the summer of 1934, Salem used 6.01 m.g. and Beverly 3.67 m.g., a total of 9.68 m.g.

The populations of the two cities, as shown by recent census figures are as follows:

Year.	Salem.	Beverly.
1925	42 821	22 685
1930	43 287	25 086
1935	43 472	25 871

Quality of Water. The early records show that Wenham Lake water had but slight color for a natural surface water. As a rule the color was less than 10 p.p.m. and the average for the eight years prior to 1895 was 10 p.p.m. Following the completion of Longham Reservoir in 1895 and the discharge of water from this source into Wenham Lake, the color of water drawn from the lake was much higher, particularly during the years just prior to 1913. With the introduction of Ipswich River water in 1913, there was a marked increase in color. Measurements of the color of the water from the several sources are summarized in Table 2, for the period 1915 to 1934, inclusive.

In general, the color of Wenham Lake water is high during the winter because of the highly colored water added from other sources and because

TABLE 2.— COLOR OF WATER FROM SALEM AND BEVERLY SOURCES OF SUPPLY SUMMARIZED FOR 1915 TO 1934.
(Color in parts per million.)

	Ipswich River.	Longham Reservoir outlet.	Wenham Lake south end.
Number of tests	214	216	226
Average color	89	115	40
Per cent. of tests in which color was			
Between 11 and 25	1.4	0	8.8
Between 26 and 50	17.8	5.1	87.9
Between 51 and 100	56.5	50.0	9.3
Over 100	24.3	44.9	0

of the inability of natural processes to reduce the color while the lake is frozen. By May, the color begins to drop and gradually lowers until raised again by the introduction of water from Ipswich River or Longham Reservoir in the Fall.

Objectionable tastes and odors have been the cause of complaints by water consumers. Odor-producing algæ such as *Anabæna* and *Cœlosphærium* have grown in abundance in Wenham Lake and *Asterionella* as well as other organisms have been present also in large numbers. On several occasions a larger number of organisms has been found in the distribution reservoirs than in Wenham Lake. This is particularly true of the Beverly reservoir, which is an open reservoir* with earthen banks paved with riprap, whereas the Salem reservoir is of concrete and covered.

A part or the whole area of Wenham Lake has been treated at times with copper sulphate, and during the summer of 1935 water drawn from the lake has been chlorinated. All water taken from Longham Reservoir or Ipswich River has been treated with chlorine before its discharge into the lake.

Fishing being prohibited in Wenham Lake, the fish have accumulated at times to the point of being a nuisance. To remedy this difficulty, the State Department of Conservation has removed fish by trapping and placed them in waters open to public fishing within a radius of twenty-five miles. As a precaution, each man in the crew doing the work was tested to see if he might be a typhoid carrier, and the public was excluded from the areas while the work was in progress.

Trouble has been experienced from "red water" and from stains on plumbing fixtures caused by corrosive water due indirectly to the decomposition of organic matter in the stagnant bottom water of the lake and in the water in parts of the distribution systems where organic matter has accumulated and where there is little circulation of water. Complaints have been made also of dirt in the water.

With water of such poor physical quality it is not surprising that available wells and springs have been drawn on for drinking water, and that the sale of bottled water has flourished.

TREATMENT PLANT.

The water treatment plant is located at the southerly end of Wenham Lake near the pumping stations of the two cities:

Intake. The existing Salem intake, a concrete structure built in 1915, has been taken over by the Board, to serve as an intake for the new low-lift pumping plant which pumps water from the lake to the treatment plant. The intake includes screens and a 36-in. cast-iron suction line, and is designed to draw water at points 10 and 25 ft. below the full lake level.

---

*A large covered reservoir is now (1936) being built.

Low Lift Pumping Station. The superstructure, 20 by 35 ft. in plan, inside, is of red brick of colonial type on a concrete substructure. (See Fig. 2.) The motor room is above ground and the pump room below ground.

The equipment is as follows:

One 12-in. suction, 10-in. discharge, vertical shaft centrifugal pump, Dayton-Dowd Company, rated capacity 2 850 g.p.m. against total head of 53 ft., speed 1 200 r.p.m., direct-connected to 50-h.p. synchronous motor, Electric Machinery Mfg. Co., 3-phase, 60-cycle, 4 000-volt alternating current, direct-connected exciters.

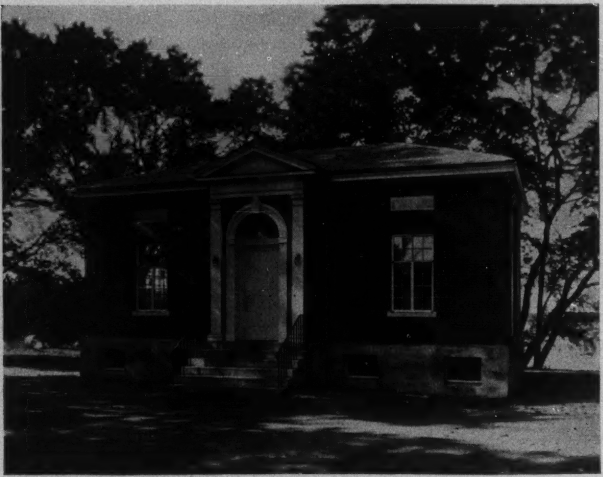

FIG. 2. — LOW-LIFT PUMPING STATION, SALEM AND BEVERLY.

One 14-in. suction, 12-in. discharge, vertical shaft centrifugal pump, Dayton-Dowd Company, rated capacity 4 725 g.p.m. against total head of 48 ft., speed 900 r.p.m., direct connected to 75-h.p. synchronous motor, type similar to the smaller unit.

One 16-in. suction, 14-in. discharge, vertical shaft, centrifugal pump, Dayton-Dowd Company, rated capacity 5 850 g.p.m. against total head of 52 ft., speed 720 r.p.m., direct connected to 100-hp. synchronous motor, type similar to the other two units.

Two Nash Hytor vacuum pumps, size L-2, direct-connected to 3-hp. motor, 3 phase, 60 cycle, 110–220 volt alternating current, capacity 25 cu. ft. per minute at 16 in. of mercury vacuum. The units are operated by four liquid-level control switches, Minneapolis-Honeywell Regulator Co., No. L-620-1 low-water cut-off mounted on a steel vacuum tank 30 in. diameter by 60 in. long, connected to the pump-suction main.

One automatic motor-driven vertical shaft centrifugal sump pump, Yeomans D-3.

Electric power from the Beverly Gas and Electric Company, is brought to an outdoor substation near the low-lift pumping station by two different routes, one for normal use and one to be used in case of failure of the other. The substation transforms the power to 4000-volts, 3-phase, 60-cycle, alternating current, which is expected to be the primary voltage in this district in the near future and hence was selected as the operating voltage of the principal electric-power-driven units. The primary-voltage electrical control-equipment and switchboards were manufactured by Roller-Smith Company of Bethlehem, Pa.

The service-entrance oil-switch unit, disconnecting switches, relays, current and potential transformers, meters and appurtenances and low-lift pump-motor control equipment are installed in six factory-assembled, safety-type steel cubicles located in the motor room of the low-lift pumping station and arranged to form a complete dead-front switchboard. The equipment provides for remote control of the low-lift pumps from the Filter Plant with automatic, reduced-voltage starting and control of the field.

The motor starters in the Chemical House for the wash-water-pump induction-motors are also installed in two safety-type, steel cubicles.

Transformers are provided at each building to furnish the 220-volt and 110-volt service required for small motor and lighting services.

Force Main and Venturi Meter. The water lifted by the pumps in the low-lift pumping station will be discharged through a 24-in. cast-iron pipe 900 ft. long to the mixing tanks in the chemical house. The rate of pumping will be measured and recorded by means of a 24-in. by 12-in. Venturi meter with indicating-registering and recording instrument, made by Simplex Valve & Meter Co.

The force main also includes an automatically controlled type R-K butterfly valve, 30-in. size, designed to regulate the height of water on the filters and prevent overflowing them. This regulator was made by Ruggles-Klingemann Mfg. Co. of Salem and is mechanically operated by float-controlled relay power-motor.

Mixing Tanks. There are two mixing tanks of concrete, each 18 by 18 ft. in plan and 17.5-ft. water depth, designed to be operated in series, in parallel or individually, as desired. Each tank is equipped with a slow-motion wooden stirrer driven by a 2-h.p. electric motor through a 400 to 1 gear reduction and through a Reeves No. 00, 4 to 1 speed reducer. Motor speed 1 140 r.p.m. The flow through these tanks is against the rotation of the stirrers and also vertical. In these tanks the water will be thoroughly mixed with the chemicals, the speed of the stirrers being regulated to form the optimum size of alum floc. The capacity of the two tanks is equivalent to a storage of 15 minutes at a rate of 8 m.g.d.

Coagulation Basins. There are four covered concrete basins each 95 ft. long by 33 ft. wide, inside, by 15-ft. average water depth and having a combined capacity equivalent to 4 hours storage at 8-m.g.d. rate of flow. Each basin is divided longitudinally by a wooden baffle which causes the water to flow the full length of each basin and back. The basins will be operated in parallel. Gates are provided to control the two inlets and a drain in each basin, and there are a weir and a channel to collect the settled water.

When a basin is taken out of service for cleaning, the supernatant settled water can be drawn off and pumped into the influent conduit leading to the other basins. For this purpose the following unit has been installed in the basement of the chemical house.

One 6-in. suction 5-in. discharge horizontal shaft, double suction centrifugal pump, Dayton-Dowd Company, rated capacity 400 g.p.m. at total head of 23 ft., 1 150 r.p.m., direct-connected to a 5-hp. General Electric induction motor.

The basins are built of reinforced concrete with a flat slab roof covered with earth and with earth banks on the sides.

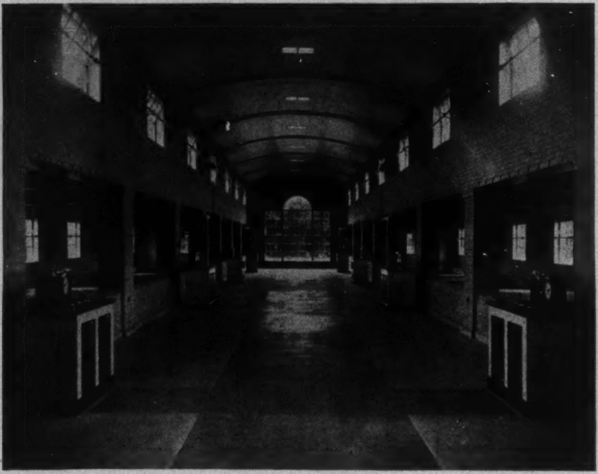

FIG. 3. — INTERIOR OF FILTER HOUSE, SALEM AND BEVERLY.

Filters. There are eight concrete filter boxes, arranged four on each side of the pipe gallery, and each 18 by 23 ft. in plan inside and 9 ft. depth of water. (See Fig. 3.) The wet sand area of each is 366 sq. ft. At the conventional rate of filtration of 125 m.g.d. per acre, each filter will have a normal capacity of 1 m.g.d., or a total of 8 m.g.d. for the plant. It is expected that a rate of 150 m.g.d. per acre will be practicable, thus making the capacity 10 m.g.d.

The underdrainage system consists of 3-in. cast-iron pipe laterals, 6 in. on centers, connected to a central concrete conduit 2 ft. 6 in. wide by 2 ft. 10 in. high. The pipes are perforated with two rows of ¼ in. holes, 6 in. on centers staggered and pointing down on a line 22½ degrees each side of the vertical.

The lower part of the filter consists of four layers of selected screened gravel as follows:

Layer.	Depth Inches.	Size of opening through which gravel will pass.	Size of opening on which gravel will be retained.
Bottom	7	2½-in. circular ring	1½-in. circular ring
2nd	4	1½-in. circular ring	¾-in. square mesh
3rd	4	¾-in. square mesh	¼-in. square mesh
4th	3	¼-in. square mesh	No. 12 mesh U. S. Standard sieve

The bottom layer is measured from the concrete floor and includes the cast-iron pipe laterals. The two larger sizes of gravel were obtained in part from the Walpole Sand & Gravel Co., and in part from a sea-shore deposit of shingle. The remainder came from the Lynnfield pit of the Essex Sand and Gravel Co.

The filter sand, obtained from Plum Island, Mass., was specified to have an average effective size of not less than 0.35 m.m., nor more than 0.45 m.m., and a uniformity coefficient of not more than 2.5. The filters were designed to have a depth of sand of 30 in., but at the outset 3 in. more were added to permit scraping 1 in. from the surface after washing in place and to allow for consolidation.

The depth of water over the sand is 5 ft. with 12 in. of freeboard.

There are three steel wash-water troughs in each filter, located 6 ft. on centers, with the top edges 2 ft. 6 in. above the surface of the sand. The troughs have sloping bottoms draining to a main gutter along the side.

The discharge of each filter is controlled by a 12-in. direct-acting filter-rate controller and diaphragm unit with rate-setting device, made by Builders Iron Foundry, range of capacity is from 750 000 to 3 000 000 g.p.d.

The controls of each filter are placed in an operating table located in front of each filter on each side of the central operating gallery. The hydraulically-powered valves on the influent, effluent, wash-water and drain pipes are each controlled through a four-way piston-type valve operated by a vertical lever through a cam supported on the top of the table. Indicators showing the valve positions are worked by bronze cables running over sheaves.

The tables have 1¼-in. black slate tops and bases, with ⅞-in. Italian marble ends and stiles, and two black Transite doors in front. Electric fixtures and other fittings are chromium plated. The tables were made by Norwood Engineering Company of Florence, Mass.

Indicating loss-of-head and recording rate-of-flow gages, 8-in. size, with diaphragm-pendulum units were made by Builders Iron Foundry.

Wash Water. Filtered water for washing the filters is provided by two centrifugal pumping units as follows:

Two 18-in. suction, 16-in. discharge horizontal shaft double suction centrifugal pumps, rated capacity 8 000 g.p.m. each at a total head of 50 ft., speed 860 r.p.m., direct connected to 125-h.p. General Electric induction motors, Form KT, 3-phase, 60-cycle, 4 000-volt alternating current.

The pumps have a suction main from the filtered water reservoir.

The rate of discharge is governed by a 24-in. wash-water rate-controller with type MGO indicating, recording and totalling instrument made by Simplex Valve and Meter Company. This controller has a range from 3 to 12 m.g.d.

The filters have been designed to be washed at a rate of 36 in. vertical rise of wash water per minute or less.

Filtered-Water Reservoir. This structure is of concrete, inverted groined-arch floor, groined-arch roof and semi-elliptical arched side walls. (See Fig. 4.) The inside dimensions are 217 ft. square by 13.25-ft. depth of water. The capacity is 4 m.g.

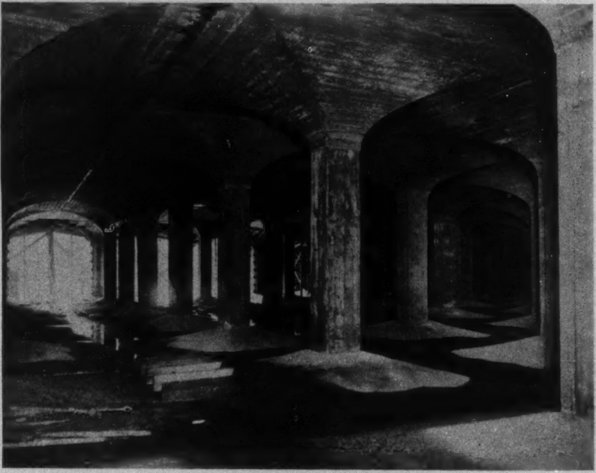

FIG. 4. — INTERIOR OF FILTERED WATER RESERVOIR, SALEM AND BEVERLY.

The groined-arch type of construction was used to provide a maximum of labor with a minimum of expense for materials. It is, also, an advantageous type of construction where the structure is completely covered with earth, and below the surface of the ground and where the foundation material is firm.

There are 144 concrete columns, 16 ft. 7 in. on centers, 24 in. square, each supporting a roof unit. The height from the low point in the floor to the crown of the roof is 15 ft. 5 in.

The height of water in the reservoir is recorded in the chemical house by a 10-in. liquid-level recorder of the diaphragm type made by the Foxboro Company.

A 30-in. and a 24-in. main lead from this reservoir to the pumping stations of Salem and Beverly respectively. Thus the filtered-water reservoir serves as a suction reservoir for the pumps which force the filtered water into the distribution systems of the two cities.

Chemical Handling. Ground sulphate of alumina, powdered soda ash, or hydrated lime, and activated carbon will be discharged into the water by means of type MOF electric-motor-driven dry-feed chemical machines made by Wallace & Tiernan Co., Inc. Each machine has a hopper which extends from the mixing tank room to the second floor overhead where the chemicals are stored. A spare machine is provided for emergency use.

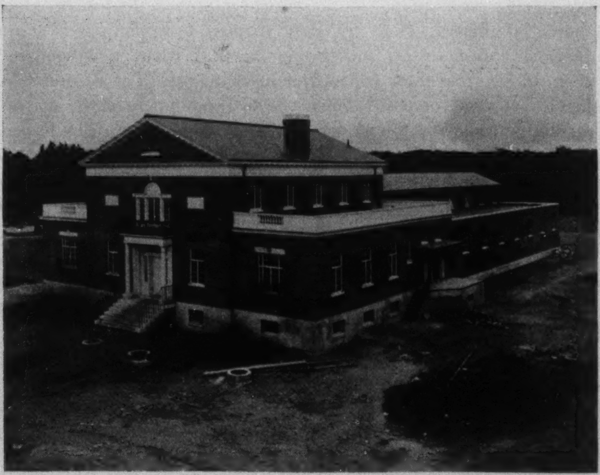

FIG. 5. — CHEMICAL AND FILTER HOUSES, SALEM AND BEVERLY.

Chlorine will be applied either as pretreatment or after filtration by means of a visible-vacuum manually-controlled, solution-feed chlorinator, type MSV-M, A-328 assembly of 60-lb. per 24 hours capacity made by Wallace & Tiernan Co., Inc.

Ammonia will be fed by means of a direct-feed manually-controlled ammoniator, type MDPA-M of 35 lb. per 24 hours capacity, also made by Wallace & Tiernan Co., Inc.

Chemicals will be brought to the plant in trucks and raised to the storage floor by a 6 ft. 6-in. by 5-ft. platform, 2 000 lb. capacity automatic, electrically-operated freight elevator made by F. S. Payne Co.

Buildings. The chemical house, consisting of a basement, largely below ground, and two floors above ground, is 51 ft. 8 in. by 68 ft. 2 in. in plan, built of red brick with white trimmings of Colonial design in keeping with the old houses of Salem and Beverly. (See Fig. 5.) The building houses on the ground floor an entrance lobby with an ornamental fountain which serves as the "show window" for the plant's finished product; an office where records can be prepared and filed and where are located the recording instruments of the main Venturi and wash-water meters, also the remote-control switches for stopping the centrifugal pumps in the low-lift station; a chemical laboratory, 27 ft. by 15 ft. in plan, fully equipped for water examinations and analyses; and the mixing-tank room in which are the dry chemical-feed machines and stirrer mechanisms. The second floor is the chemical-storage room with openings to the hoppers of the machines, also a chlorine room for the chlorinator and ammoniator. The basement includes the oil-fired steam boiler, the butterfly valve, the wash-water pumps, pressure-water pumping units, vacuum priming-system for these pumps, wash-water rate-controller, settled-water pump, some electrical control-apparatus, piping and the transformer room.

Directly adjoining the chemical house, in reality a part of the same structure, is the filter house, 59 ft. by 100 ft. 6 in. in plan, completely housing the eight filter units and operating floor, and below that the pipe gallery, 18 ft. wide and 100 ft. long.

The buildings have reinforced-concrete structures, reinforced-concrete floors and structural-steel frames. The pitched roofs are of slate laid on gypsum plank, and the flat roofs are tar and gravel on a concrete deck.

Miscellaneous Equipment. The vacuum priming-system for the wash-water and pressure-water pumps consists of

One Nash Hytor vacuum pump, size MD-2A, direct-connected to a ¾-h.p. electric motor, capacity 6 cu. ft. per min. at 16-in. mercury vacuum.

One Nash Hytor vacuum pump, size L-2, direct-connected to a 3-h.p. electric motor, capacity 25 cu. ft. per min. at 16-in. mercury vacuum.

One steel vacuum tank 20 in. diameter by 3 ft. long, equipped with liquid-level control switches of the Minneapolis-Honeywell type.

One steel vacuum tank 30 in. diameter similar to the above.

The pressure-water system serving the chemical-feed machines, chlorinator, ammoniator, wash-water rate-controller and hydraulic valves comprises the following:

One Burks self-priming pump, Fig. 1415B 2 in. by 1½ in. direct connected to a 3-h.p. electric motor, 3 440 r.p.m. capacity 40 g.p.m. at 120 ft. total head.

One Jennings single-suction centrifugal pump, size S1½D, direct connected to a 7½-h.p. electric motor, capacity 100 g.p.m. at 160 ft. total head.

One galvanized steel pressure tank of 220 gal. capacity.

Wash-Water Lagoons. Three open lagoons operated in series receive the the dirty wash-water from the filters and the sludge from the coagulation basins. The first two lagoons have an area of about 30 000 sq. ft. each and are 4 ft. deep. The third lagoon has an area of 50 000 sq. ft. and is 6 ft. deep. Water passing through the third lagoon, overflows to Wenham Lake. In this way, the wash-water is recovered after clarification by sedimentation in the lagoons.

The lagoons were formed by building dikes in the swamp adjoining the Lake. The swamp was virtually a floating mass of muck and peat as much as 30 ft. deep in places. Building of the dikes caused some of this peat to sink to hard bottom and some to be pushed out in front of the fill. Paced spillways are built in the dikes for the overflows, and the exposed face of the dike in the lake is paved with 12-in. riprap to prevent erosion due to wave action.

CONSTRUCTION.

During the latter part of August 1934, Mayor George I. Bates of Salem obtained approval of the Massachusetts ERA Administration for a relief labor project for the construction of the water-treatment plant. Following an intensive campaign, bond issues were authorized by the two city governments, construction drawings were started August 28, and on September 21 construction began. The speed with which this project was organized and men put to work, illustrates forcibly the advantages of the ERA program over the PWA with its attendant time-consuming red tape and delays. Men were at work several weeks before the drawings were completed. Owing to the approach of freezing weather and the large volume of earth excavation required before concrete could be placed, it was decided to do as much of the excavation as possible, by machinery.

This plant is built near the shore of Wenham Lake, and on that account special precautions had to be taken to prevent pollution. A sanitary building was constructed and a sewer-connection laid to a nearby Beverly sewer. An existing building was moved to the site and remodeled for an office. Other temporary buildings were put up for a mess hall, tool room and first-aid room, a cement shed and a carpenter shop. Sufficient land for the permanent plant was already owned by the cities, but additional land was rented for construction purposes. Four trucks and a concrete mixer were purchased, but all other major pieces of construction equipment were rented. Nearly all small tools and supplies were purchased. Materials of construction were bought under contracts awarded after competitive bidding.

All of the unskilled labor and most of the skilled labor came from the employment relief lists and were paid therefore by the ERA. The Water Supply Board carried a portion of the expense of the technical staff and some labor costs for overtime work, etc. Except in the case of the non-relief men, a few full time foremen, the clerk of works and the material clerk, a man worked not over 24 hours per week, 8 hours per day. One shift worked 8 hours per day for 3 days in one week, then worked the next 3 days in the second week, and then was laid off for 6 days. The next 6 days were then worked by the second shift. At the height of the work, each shift contained about 250 men. The rate of expenditures for labor and the number of men employed at various times are shown in Figure 6. Periodic reductions in payrolls and in the number of men employed was the result of the administration of the funds as allotted monthly rather than the needs of the work.

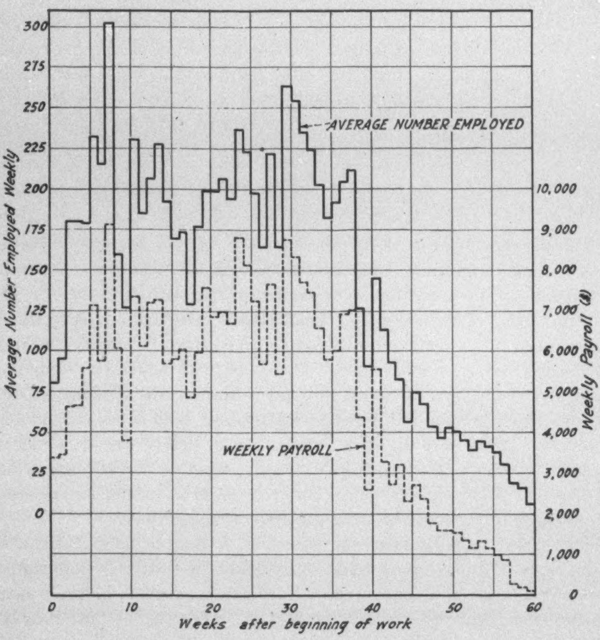

FIG. 6. — NUMBER EMPLOYED WEEKLY AND PAYROLL DURING CONSTRUCTION.

Winter Construction. The project was carried on throughout the winter with only four or five days of shutdown because of stormy weather and snow. Low temperature delayed the start of concreting operations on a number of days, but rarely for more than one half hour. There were 32 days on which the temperature dropped to 10°F. or below, and of these, 14 days on which it went to zero or below.

Heating Equipment. Two 75-h.p. boilers were used to provide steam. Water for concrete was heated by bleeding the steam into water in elevated steel tanks. Sand was warmed by steam bleeding from a system of 1½-in. pipe grids with ⅛-in. holes 18 in. on centers laid on a wooden platform on which the sand was stored until ready for mixing with the other concrete materials. In general, the stone aggregate was not heated, but at times tarpaulins were used as covers to keep out snow.

Frost and Ice. Snow and ice in the forms and stone piles were removed by steam from a pipe nozzle on the end of a hose line. Hot water was used effectively to remove the thin layers of frost from the ground and from forms upon which concrete was to be placed. Where frost to be removed from the soil had penetrated more than a few inches, perforated 1½-in. pipes were laid about four feet apart and covered with tarpaulins and steam supplied for from one to three days, depending upon the thickness of frozen ground. Experiments were tried with oil-burning salamanders for removing frost and ice from the ground inside the coagulation basins, but these were unsuccessful because of inability to confine the heat near the surface.

Temperature of Concrete. Using warmed sand and hot water, little trouble was experienced in producing concrete at a temperature of 70°F, even with air temperatures at zero or below.

Curing Concrete. With one exception, wet steam was used to maintain the temperature of the concrete until it had obtained the desired strength. In the case of walls and columns, this was done by bleeding steam from perforated pipes next to the forms within enclosures built with tarpaulins. Concrete in slabs, beams and arch-roof construction was cured by enclosing the space beneath and covering the top surfaces with tarpaulins supported a foot or so above the concrete and then bleeding wet steam both beneath the supporting forms and beneath the covering tarpaulins. In general, high-early-strength cement was used after freezing weather set in. All concrete made with high-early-strength cement was kept warm until it was 72 hours old.

During the early part of December, the concrete walls and beam supports for the entrance steps of the low-lift pumping station were placed, using standard cement. This concrete was of satisfactory temperature when placed and was protected from cold only by the forms and a tarpaulin for a period of 10 days, when upon examination it was found to be frozen and with practically no set or hardness. It could be readily dug out with a pocket knife. A coke-burning salamander was then placed beneath the forms and a temperature of about 90°F maintained for 14 days, after which, upon examination, the concrete was found to be hard and dense. The forms were then stripped and the masonry exposed to the weather. No scaling, crumbling, checking or other noticeable defect is now apparent on the surface of this concrete which probably froze before it obtained its initial set.

In a few instances, to prevent freezing, rye straw was used to cover the concrete and foundation soil which was prepared in advance of the erection of forms. This was unsatisfactory because of freezing of the straw covering following rain or melting snow. It was difficult thoroughly to remove all the straw where it had been placed on previously poured concrete. The straw also constituted a serious fire hazard.

Construction Methods. Heavy excavations were made with gasolene-powered shovels and trucks. Deep trench excavations were made largely by a clam-shell-bucket excavator. Much of the material moved in the construction of the lagoons was by a drag bucket excavator. Finished excavations for foundations and pipe lines were made by hand labor.

Concrete Handling. Aggregates were supplied to the mixer loading-hopper by wheelbarrows from stock piles. Mixed concrete was transported to the forms in concrete buggies on plank runways.

Brickwork. Brickwork in building walls was carried on during mild days of the winter. Frost was removed from the bricks before using by stacking them around coke-burning salamanders. Newly-laid brickwork was protected from cold by a wind break of "sisalcraft" paper on wooden framework outside the stagings, and by using coke-burning salamanders at from 6- to 8-ft. intervals on each side of the wall until the mortar had set hard.

Labor Cost. The cost to the ERA for labor for the construction of the filter plant and lagoons, exclusive of labor for grading, roadways, and walks, was $293 150.

The following scale of wages was in effect.

	Dollars per hour.
Unskilled	
Common Labor, Watchmen and Light Truck Drivers	0.50
Semi-Skilled	
Heavy Truck Drivers	0.60
Jack Hamer Men	0.65
Mixer Operators; Pump Men; Electricians Helpers	0.70
Plumbers Helpers, Pipe Workers, Steamfitters Helpers	0.75
Mason Tenders	0.80
Skilled	
Compressor Operator	0.75
Mechanics	0.90
Painters; Glaziers	1.00
Electricians	1.05
Carpenters; Equipment Erection Men	1.10
Roofers; Lathers	1.12½
Sheet Metal Workers	1.17½
Blacksmiths; Steam Fitters; Plumbers; Structural Steel and Reinforced Steel Men, Light Iron Workers, and Riggers	1.20
Masons; Plasterers and Cement Finishers	1.25
Hoisting Engineers; Shovel and Crane Operators	1.37½
Later changed to	1.42½

Transitman	0.75
Rodman	0.60
Painters (on Supplemental)	0.75
Shorers; Trench Bracers	0.70
Pipe Caulkers	0.75

The unit labor costs, exclusive of overhead and supervision, on some of the major items were as follows.

	Mixing and Placing Dollars.	Forms Dollars.
Plain concrete in reservoir floor — per cu. yd	3.76	2.26
Plain concrete in reservoir columns, walls and roof — per cu. yd.	4.04	7.25
Reinforced concrete in pumping station substructure — per cu. yd.	4.52	8.08
Reinforced concrete in coagulation basin — per cu. yd.	5.38	5.98
Reinforced concrete in chemical and filter buildings including substructure and floors and roofs — per cu. yd	8.70	9.50
Placing reinforcing steel in coagulation basin — per ton	24.25	...
Placing reinforcing steel in pumping station substructure — per ton	28.30	...
Placing reinforcing steel in chemical and filter building — per ton	42.60	...
Erection of structural steel — per ton	38.90	...
Brickwork (including glazed tile work and granite trim) — per 1000	50.40	...

Cost of Curing Concrete and Heating Materials. Heat for concrete work was used from November 6, 1934 to March 24, 1935, during which period 4645 cu. yd. were placed.

The average unit cost of this protection, exclusive of overhead and supervision was $2.58 per cu. yd. subdivided as follows:

Item.	Dollars per Cu. Yd.
Labor	1.21
Equipment rental	0.17
Coal	0.60
Tarpaulins	0.47
Pipe fittings, etc	0.13
Total	2.58

Snow Removal. There were six days when snow fell in sufficient amounts to interfere with construction operations. Exclusive of the cost of removing ice and snow from forms on a few days at the start of concreting operations in the morning, which is included in the cost of mixing and placing concrete as given previously, the labor cost of removing snow, clearing roads and paths was $1 965. The total snowfall was 45 in. as measured at the Salem pumping station rain-gage located on the lot adjacent to the job.

Cost of Project. The cost to the two cities for administration, engineering, superintendence, materials, equipment and a small amount of labor was covered by bond issues amounting to $351 000, of which Beverly issued one-third and Salem two-thirds. All of this amount will have been expended when the grounds about the plant have been completed. This includes, also, the purchase of the existing intake structure and suction pipe from the city of Salem. The balance of the cost, for labor, was provided through ERA projects and recently by a WPA grading project.

The total costs are as follows:

ERA	project — original	$250 560
	First supplemental	24 801
	Second supplemental	4 324
	Lagoon project	13 464
WPA	Roads, grading, etc., estimate not completed	10 000
Bond issues		351 000
		$654 149

Acknowledgments. Acknowledgment is made of the assistance of Mr. James O. Phinney, Clerk of Works, in compilation of cost records from which the data given herein were determined; also, for helpful suggestions from Mr. A. James Walsh, Superintendent of Construction. Credit is due, also, to Austin B. Henderson and Harold V. Robichau, assistant engineers and to the foremen and skilled mechanics employed on the work for the excellent construction produced under conditions that were not only unusual but, at times, rather trying.

WATER DEPARTMENT
REGULATION OF WATER PIPES WITHIN BUILDINGS†

BY STEPHEN H. TAYLOR.*

[Read February 20, 1936]

It is the opinion of the author that insufficient attention has been given in the past by water works officials to water piping and fixtures inside of the taker's premises. Until last year, we in New Bedford have felt that when we assured ourselves that service pipes up to and including the meter were of proper material and properly installed our responsibility and jurisdiction ended and that what was installed inside of that point was wholly the affair of the owner and his plumber. I think it is safe to say that most of the other communities in this country have taken the same attitude.

As a result, we find that in many cases inferior material and workmanship have been employed and fixtures so designed as to introduce a danger to health through pollution of the supply within buildings caused by siphonage or gravity backflow of polluted water from bowls and other fixtures into the water supply piping.

When building was booming and numerous speculators were building houses to sell, it was an unfortunate fact that in many cases the speculator's idea was to build as cheaply and sell at as high a price as possible. This resulted in a great many buildings being piped for water with poor materials and fixtures which were installed in many cases by incompetent workmen.

It is a well-known fact that the surface water which furnishes the supply to New Bedford is rather active and quickly fills wrought iron and steel pipes with rust and tubercles. The same is true of many other communities. In spite of this, many buildings have been piped with this type of material, with the result that after comparatively few years have elapsed, water cannot be drawn through more than one fixture at a time and that one delivers only a weak supply. That part of the service which is installed by the water department in New Bedford is of lead in sizes up to 1 in.; and copper or cast iron in the larger sizes. In most cases we have installed the service up to the meter which is usually in the cellar at the point where the service enters the building.

When the complaint of poor flow comes to us we clear the tap if necessary and prove that the supply is ample to the meter and that the trouble is caused by the steel piping inside the building filling with rust and tubercles. This means many unnecessary visits and takes considerable time of our employees. When the owner finds that his only remedy for the trouble is to repipe the entire building, to say that he is naturally somewhat disturbed is stating the case mildly; as in most cases the piping is concealed within the walls and replacement is an expensive proposition. We have also found that there is a growing tendency to install fixtures so designed that polluted water from them will flow back into the water supply pipes either by gravity or siphoning in case the pressure is reduced by heavy draft or the water is shut off either in the building or in the street.

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*Superintendent, New Bedford Water Works, New Bedford, Mass.

†Members of the Association are invited to correspond with Mr. Taylor's committee appointed to consider the advisability of water department control of interior piping and fixtures.

In an effort to improve these conditions the Water Board adopted a set of rules and regulations, effective June 1, 1935, governing the installation of house piping, which we feel will benefit the water department and more especially the public. The following are some of the principal requirements:

All services must be laid by the Water Department from the main to the meter.

No cross-connections are allowed between the city supply and any other supply which is not approved as potable by the State Department of Public Health, except when properly protected by double check valves of an approved type. Such installations must be inspected and tested by the Water Department at such intervals as it shall determine.

Plans of proposed new installations or alterations of existing systems must be submitted to and approved by the Water Department before starting work.

All inside piping must be installed under the supervision of a master plumber except in plants where competent pipers are regularly employed and except that connections to water heaters and similar equipment may be made by persons regularly engaged in installing such equipment; all subject to inspection and approval by the Water Board.

The city ordinances place the supervision of hot water tanks and water heaters under the jurisdiction of the Board of Health. That department works in coöperation with our department regarding this equipment and has established rules requiring such equipment to be installed in a manner which will be safe and prevent forcing hot water back to damage meters.

All master plumbers are required to register their name and business address at the Water Board office.

All installations are tested under city pressure in the presence of our inspector before acceptance.

All pipes less than 4-in. in diameter must be of lead, brass, copper or other non-ferrous material. Pipes 4 in. and larger in diameter may be of cast-iron properly coated and lined with material approved by the Water Board.

Standard minimum weights are established for each kind of pipe allowed, and standard minimum sizes are established for each tenement and fixture.

No pipes which have previously been used for other purposes are allowed to be employed for water service.

It is required that the service be carried full size to the point where the last branch is taken off. Accessible separate shutoffs are required in the basement for each tenement and for each hot water tank.

Concealed piping, tanks, etc. must be properly protected against freezing and must be tested before being concealed. The bottom of flush tanks for water closets or urinals must be above the overflow level of the fixture when the drain is obstructed.

All flushometer valves must be equipped with a vacuum breaker of approved type.

We require that when the water is delivered to any receptacle below the overflow line of the receptacle when the drain is plugged, provision be made to prevent backflow from the receptacle, by siphon breaker, check valve or other approved method.

The inspection has been placed in the hands of a master plumber of long experience who has the respect and confidence of all master plumbers. He is a full-time employee of the Water Board and has the complete co-operation of the Plumbing Inspector of the Board of Health. The rules have been in effect since June 1, 1935, and the results have been very satisfactory. The master plumbers coöperate very well with us as the regulations protect them against unfair competition of unlicensed men and inferior materials. The public gains by being assured of proper supply to approved water fixtures and the department gains by being relieved of many complaints due to improper materials or workmanship.

As far as the author knows, very few communities have made rules regulating water service piping and fixtures inside of buildings. Board of Health plumbing regulations generally concern drains only. Is it not just as essential that proper fixtures, designed to prevent pollution through backflow and provided with an ample supply of pure water, be furnished our consumers? No matter how complete the main distribution system and service connection may be, the consumer will not get the supply he is entitled to at his fixtures and the protection against pollution within his own property unless either the water or health departments see to it that proper interior piping and fixtures are installed by competent workmen.

Our City Solicitor has ruled that the supervision of the entire water supply except water heaters and hot water tanks up to and including proper fixtures is within the jurisdiction of the Water Department. After serving its purpose in the fixture the water becomes drainage and then comes under the supervision of the Board of Health through its Plumbing Inspector.

Incidentally it is interesting to note that in spite of the fact that no new building is going on, in the 8½ months since these rules became effective, about 700 permits for alterations and replacements have been issued.

It may be interesting to cite two outstanding cases of potential pollution that have recently come to the attention of our inspector.

In a large addition to our high school, housing several thousand pupils, several laboratory sinks were installed on the fourth floor with an ordinary faucet on one side and a gooseneck faucet working on a ground joint swivel on the other side. Both fixtures were below the overflow level of the sink. The polluted contents of these sinks could very readily enter the supply pipe if for any reason the pressure was low and could be distributed throughout the building to the drinking water. (See Figure 1 of Discussion.)

In a good sized department store, a soda and lunch counter was installed. Behind the counter is a spoon and ladle washer with waste and supply connections in a single unit brought in through the bottom. The bowl stands about one-third full, and spoons and ladles are dropped into it. At intervals the water is changed. Naturally grease collects in the bowl, requiring the use of strong solvents to remove the accumulation. This mixture could easily flow into the supply line, if the pressure was lowered, and be fed to other fixtures, including the carbonator which supplies the soda fountain. (See Figure 2 of Discussion.)

These cases and many others show the need of constant vigilance on the part of someone, and we in New Bedford have decided that the Water

Department should assume this responsibility as there is a possibility that pollution from such sources may get back into our mains by siphonage or gravity when it becomes necessary to shut off the street mains.

I realize that this is an innovation in water works affairs, but we believe it is one which is worth while, and I hope that this paper will start some discussion and start other people thinking along the same line.

It should be understood that rules governing pipe materials that apply to one community may be all wrong for another one. For instance, the action of some waters on lead pipe will cause lead poisoning. In such cases, lead pipe should be prohibited. With other waters, wrought iron and steel pipes may be satisfactory. In some cases ordinary yellow brass will not give good service. To sum up the situation, each of us should study conditions in our own community and formulate piping rules to fit local conditions; allowing the use of only such pipes as are satisfactory under these conditions. This will benefit the public and the water department.

Local ordinances must also be considered. It may be that in some communities other authorities already have jurisdiction over water piping and fixtures. If so, coöperation with that authority should be sought by the water department to remove the possibility of pollution of the public water supply by improper cross-connection between drainage and water supply by improperly designed fixtures.

Communities which are supplied by private water companies are still another problem, but I believe some method can and should be worked out to remove the potential dangers of improper piping and fixtures; perhaps by coöperation between the water company and the health authorities. In any case our coöperation with local and state health departments is important.

Please do not lose sight of the importance of that section of my discussion pertaining to pollution by cross-connections with drains and to fixtures which permit the backflow of their polluted contents through the water piping to other fixtures from which polluted water may be drawn for drinking and similar purposes, and possibly into our mains. This is our best justification for our interest in the matter, and rules governing this feature could probably be universal.

I believe it would also be well, where possible, for water departments to regulate water heaters and hot water tanks, not only on account of the danger of explosion and consequent loss of life and damage to property but to eliminate the backing of hot water through services, where damage is done to meters, and into mains. The only reason we did not include these in our regulations was that jurisdiction over them had previously been given by our City Ordinances to the Plumbing Inspector of the Board of Health. Fortunately, he has coöperated very well with us and established excellent rules regulating them.

It would be very desirable if coöperation could be established with the manufacturers of fixtures to encourage the manufacture and sale of properly designed fixtures and discourage those which are likely to cause pollution.

Discussion.

James F. Murphy.* I shall give a description of some of the more glaring examples of cross-connections with which I have come in contact during the course of building inspections.

In each instance the type of connection involved was almost certain to develop water pollution or contamination of the water supply to the several fixtures on these systems. A study of Figure 1 will show an apparent lack of thought as to what might happen through undesirable connections by the designer of a new type of table for use in a chemical laboratory. Several of these tables were installed in a laboratory of one of the newest educational institutions in the country where the designer had laid a great deal of stress on providing a clear, unobstructed top to the laboratory table. In so doing he produced a condition that might have proved disastrous at

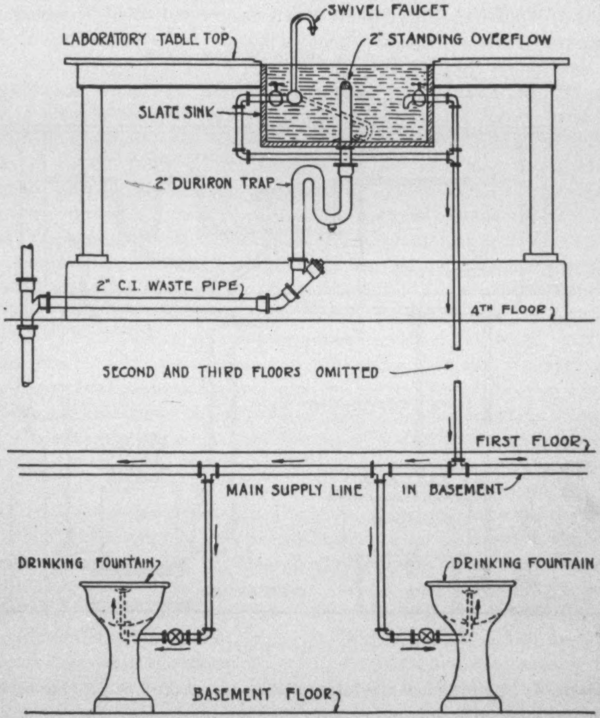
SWIVEL FAUCET
LABORATORY TABLE TOP
2" STANDING OVERFLOW
SLATE SINK
2" DURIRON TRAP
2" C.I. WASTE PIPE
4TH FLOOR
SECOND AND THIRD FLOORS OMITTED
FIRST FLOOR
MAIN SUPPLY LINE
IN BASEMENT
DRINKING FOUNTAIN
DRINKING FOUNTAIN
BASEMENT FLOOR

Fig. 1.— Cross-connection of Water Supply with Laboratory Sink Drainage.

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*Inspector of Inside Water Piping Installations, New Bedford Water Department.

some future time to some of the several thousand students at the school. A very deep slate sink was built into the table top, and provided with a cover which when placed in position entirely concealed the sink. This made a very clean, smooth, unobstructed surface but at the same time created a decidedly undesirable condition in the plumbing system. The slate sink was provided with one ordinary faucet brought in through one side and a gooseneck faucet working on a ground joint or swivel, on the other side. This latter faucet stood upright when in use, and could be swung to the bottom of the sink when the latter was to be covered to provide an unobstructed table surface.

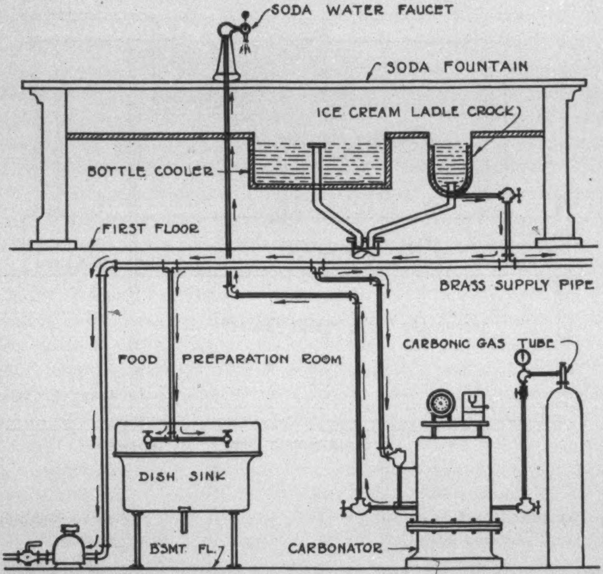
SODA WATER FAUCET
SODA FOUNTAIN
ICE CREAM LADLE CROCK
BOTTLE COOLER
FIRST FLOOR
BRASS SUPPLY PIPE
CARBONIC GAS TUBE
FOOD PREPARATION ROOM
DISH SINK
BSMT FL.
CARBONATOR

Fig. 2.— Cross-connection of Water Supply with Drainage from Soda Fountain.

Whenever it was necessary to fill the sink with water for washing purposes, or for any other reason, a standing overflow pipe could allow the water, with whatever impurities it had gathered from the sink, to rise above the faucet in the side, and also in the swivel faucet, if it had been swung downward, due to the fact that the outlet holes in the overflow pipe were well above both faucets. And again, if the waste outlet became clogged, the resultant backflow could also submerge both faucets. Thus, if the main supply were by chance shut off, the impure contents of the sink in the form of water, acids, chemicals, etc., could find their way by gravity and siphonage into the single unbranched vertical line which supplied several of the sinks. Inasmuch as the laboratory was located on the fourth floor the impurities could easily reach the drinking fountains, or any number of faucets at the fixtures on the floors below. This dangerous condition is to be remedied through the use of spouts that will be located well above the tops of the sinks.

Figure 2 refers to a condition in a large size department store where the management decided to add to its various branches, facilities for serving drinks, and luncheons. Accordingly a modern up-to-date and fully equipped soda fountain was installed. To the ordinary observer the outfit was perfection itself, but to a plumber with a mind full of cross-connections it developed that there was just one thing about the fountain that did not appeal to a person informed on this subject. There was the regular tumbler washer with a spring or self closing valve that entered the bottom of the fixture. A strong spring arrangement closed the valve after it had been opened to wash a tumbler, by pressing the inverted glass downward. Next to the tumbler washer was a spoon, scoop, or ladle crock, used for the purpose of washing the ice cream ladles. This crock had both waste and supply connections in a single unit, brought in through the bottom, and was so arranged that it stood about one-third full of water constantly to allow the cream to melt off the ladles.

This water after a time was to be discharged into the waste system, and the crock refilled by opening a supply valve that was extended out where it could be conveniently operated by hand. Naturally greasy substances from the various kinds of cream collect on the inner walls of these crocks, requiring from time to time the use of a strong solvent to remove the accumulation. And therein lies the objection to such an arrangement because, during this cleansing process the main water supply might be shut-off with the following result. The released impure waste water could flow into the main supply line, from there into the carbonator which is generally located directly underneath the fountain, and there become mixed with the carbonated water which has been generated. This impure mixture could then be delivered back to the fountain tap to be served in the drinks to the customers as long as the condition existed. In a food preparation room, located in the basement directly below the fountain, most of the mixtures were prepared for the foods served with the luncheons. The water for these mixtures was drawn from the same supply line that contained the tainted water. The condition was discovered before the fountain was placed in operation and remedied in a satisfactory manner. The supply line was carried well above the point of overflow and fitted with a double vertical check valve to prevent any chance of backflow from one part of the system into another.

Figure 3 represents an installation in a dental laboratory where several dentists and nurses were employed. It would seem almost impossible to find a more clean, wholesome, and sanitary condition than that existing in this building; where every person wore an immaculately white uniform and conditions appeared perfectly sanitary. The doctor in charge decided to do some X-ray work which necessitated the installation of a sink of acid proof material for use in developing and cleaning plates, films, etc. This sink had a side tapping near the bottom for its water supply connection. A branch fitting was inserted in this line close to the sink into which was screwed a drain valve. An upper tapping through the side of the sink served as an overflow. Both overflow and drain valve were fitted with rubber tubes which extended down part way into a galvanized iron water pail. Both of these tubes would become air-bound when the pail filled above the bottom of the tubes, thus stopping the liquid from flowing out and leaving the sink partly filled with the solution. When this condition existed the most natural thing to do was to open the supply valve.

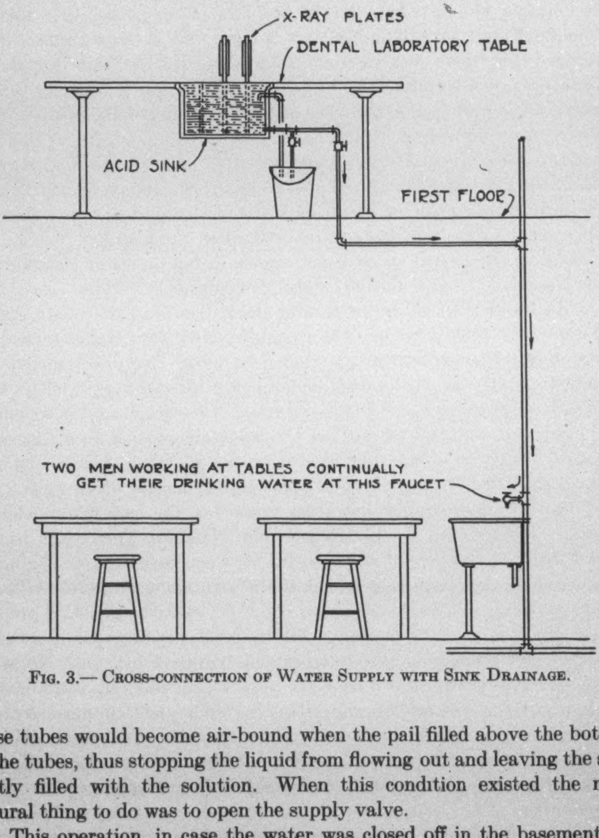
X-RAY PLATES
DENTAL LABORATORY TABLE
ACID SINK
FIRST FLOOR
TWO MEN WORKING AT TABLES CONTINUALLY
GET THEIR DRINKING WATER AT THIS FAUCET

FIG. 3.— CROSS-CONNECTION OF WATER SUPPLY WITH SINK DRAINAGE.

This operation, in case the water was closed off in the basement for any one of several reasons, would allow the solution to flow or be drawn into the supply pipe leading down to the main service line in the basement. Reference to the diagram will show that at least two dentists were working almost constantly at tables in close proximity to a sink that was supplied from the main service line, and when the condition previously described existed, it can readily be seen that the solution drawn from the sink above would flow from these faucets. In fact a great quantity of this solution could find its way into the service line to be drawn at any or every faucet in the entire building. The possibility of some disastrous occurrence being observed before the installation was completed, changes were made by the proper placing of the valves, and the introduction of syphon-breaking devices in such a manner as to entirely prevent any such happening.

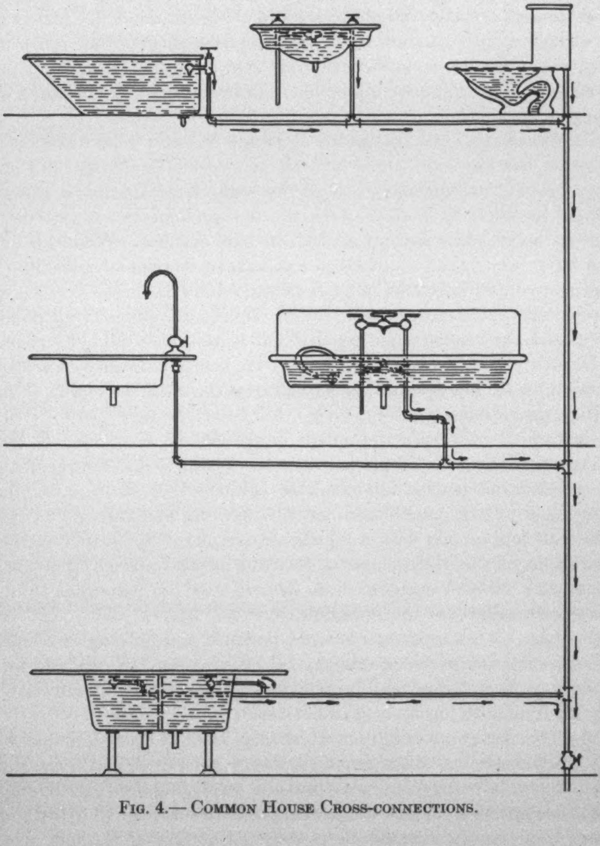

FIG. 4.—COMMON HOUSE CROSS-CONNECTIONS.

After observing Figures 1–3 and learning of the possible chances for water pollution or contamination through their incorrect connections, a person might feel that he was perfectly safe in his own home, and so long as he did not frequent, occupy or visit any of the preceding types of building he would be perfectly safe from infection due to impure water. However, reference to Figure 4 will demonstrate that in some cases almost any type of fixture in any residence or almost any other kind of building may under conditions that are likely to occur in such buildings, develop results similar to those described in the previous diagrams.

The only fixture shown in Figure 4 with faucet so arranged as to deliver water through a spout well above the top of the fixture is the pantry sink; but with every other fixture in the building so connected that waste water could, under certain circumstances find its way into the clean water piping system, it might be almost impossible to draw anything but polluted water through this faucet.

In his capacity as "Inspector of Inside Water Piping Installations" the writer has the opportunity to visit all types of buildings, and hardly a day passes but what some decidedly serious installation is observed. Changes have frequently been made at his suggestion on old systems, and incorrect connections are prohibited on new systems. While no official steps have been taken to make it compulsory to remedy unhealthy and dangerous connections such as those described in this discussion, it is quite certain that should a general survey of plumbing systems in all buildings be required, the results would be such that legislation would be enacted by the Department of Health of the State or the boards of health of the various communities to improve and remedy at least the more dangerous of many existing installations.

In fact the members and agents of the State Department of Health of Massachusetts are so deeply interested in this subject at the present time that at their instigation a committee composed of sanitarians, master plumbers, lecturers, health and water inspectors and instructors is now working in conjunction with a representative of the Sanitary Engineering Department of the Massachusetts Institute of Technology to devise and arrange an exhibit so designed as to demonstrate the disastrous results of incorrect installations on plumbing systems known today as "cross-connections." This apparatus is to be portable and is being developed as part of a statewide series of educational lectures that are planned for the enlightenment of the general public to the possibilities of infection and epidemic from such improper installations.

Another dangerous condition which may exist in every building where there is a domestic hot water supply system is the possibility of the storage tank or heater bursting from excess pressure; exploding from excess temperature; or collapsing from lack of internal pressure sufficient to withstand the atmospheric pressure exerted on its outward surfaces if through accident or otherwise the water is drawn or siphoned from the inside.

Any of these causes may result in ruining or rendering temporarily useless the water meter of the main service line by a back flow of hot water from an overheated storage tank or heater. This latter appears probably most significant in the minds of water department officials for the reason that damages from such conditions incur a considerable amount of expense for removing, repairing, testing and replacing the meters. This expense is usually charged to the consumer and in almost every case brings an appeal from payment on the grounds that the water department should guarantee and take care of the meters.

In one residence within the last few months the meter was rendered useless on two occasions in about three weeks' time, incurring an expense of about $8.00 to $10.00 on each occasion. This naturally caused a considerable amount of argument and protest by the consumer. The copper coil in the gas heater was burst the second time, although a safety valve which did not function had been installed in the cold water piping above the top of the boiler. The cause on each of these occasions was that a gas heater used for heating the water in the tank was lighted and forgotten, with the result that water in the tank became overheated to the extent that the hot water was forced back through the supply pipe, and through the meter, certain parts of which are constructed of substances that become swollen and useless when brought into contact with water heated to a high temperature.

If a properly constructed, tested and approved device known as a relief valve had been installed as part of the equipment on the tank in question, it is very likely this trouble, inconvenience, and expense might have been avoided.

The subject of relief valves has probably received more attention within the last year or two than ever before for the reason that more rapid heating devices are being used today than ever before, with the result that there has been a noticeable increase in the number of meters damaged in this manner. With some of the more efficient heaters today the entire contents of a thirty gallon tank may be heated to a high temperature in perhaps one hour's time.

An investigation of many damaged meters and boiler explosions tends to show that one of these rapid heaters was responsible for both these results at the same time, and in some localities it is now compulsory by law to test all relief equipment on every hot water storage tank, so designed and arranged as to prevent the tank from being damaged by either over pressure, excess temperature, or being collapsed by lack of internal pressure. The use of, and proper functioning of valves of this type would automatically prevent the damaging of meters by a back flow of hot water from the tank, as the relief valve would operate before the water in the tank reached the high temperature necessary to cause this trouble.

There are many types of relief valve on the market at the present time, some of which are designed for excess pressure alone, excess temperature alone, or in combinations of both temperature and pressure, and also combining the three features, excess pressure, excess temperature, and a vacuum feature which opens when a vacuum is created in the supply line and which tends to stop the siphonage, created by the vacuum, thereby preventing the boiler from being emptied in this manner. While some of these will perform in a satisfactory manner, there are others which do not operate to the satisfaction of the authorities in some localities, where stringent and correct functioning is required in order to conform to the specifications required in such communities.

A lack of positive knowledge, and information on the operation of these devices prompted the writer who has charge of the plumbing department at the New Bedford Vocational School to develop a testing and experimental set-up in the plumbing laboratory at that institution so that a certain amount of definite information could be obtained.

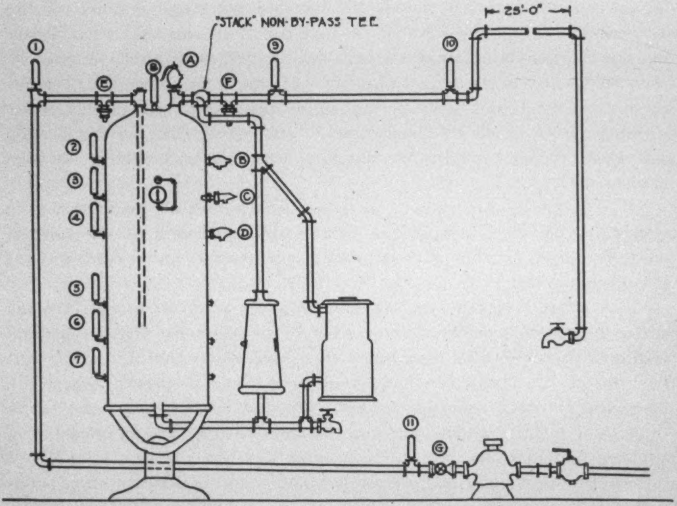

FIG. 5.— EXPERIMENTAL BOILER FOR TESTING RELIEF VALVES.

Accordingly, together with Mr. Ernest G. Parker, Inspector of Plumbing in the Board of Health and Mr. Herbert C. Reynolds, a leading master plumber and an authority on this subject, the writer conducted an intensive series of tests and experiments, in order to select valves that could be approved and recommended for use in New Bedford, Mass.

The testing apparatus (Fig. 5) consisted of a forty-gallon copper pressure boiler, in which the regular number of four tappings had been increased to twenty. These were so arranged that a relief valve could be inserted in a top or side tapping and on the same level in another tapping a thermometer, thus giving a fairly correct reading of the temperature at which each valve operated.

After obtaining such information as was possible the interested group gave a series of lectures and demonstrations of such valves as seemed to operate satisfactorily before various groups of journeyman and master plumbers, superintendent and other employees of the Water Department, and other city officials, members and agents of the Board of Health, gas company officials and employees. Most surprising of all, one entire evening and lecture were devoted to a group of ladies who expressed much interest in the knowledge they obtained pertaining to the hot water tanks which most persons are in the habit of seeing, while they know little about the possible dangerous condition that might result from a boiler installation that might be made in a careless or incorrect manner.

Figure 5 will provide a general idea of the apparatus and a short outline of some of the tests is given herewith for the benefit of anyone who may be interested in this subject.

(A) represents a "pressure relief valve" (only) which operates at 100 pounds pressure, the maximum allowed in New Bedford. To obtain a test of this valve the gas heaters were lighted; the control valve (G) on the supply line was closed and the pressure gauge in the center of the boiler registered 45 pounds. In just three minutes the pressure reached 100 pounds, and the valve operated. This tended to show the rapid expansion of the water when heat was applied and all chances of expansion or back flow were prevented by having closed the valve. From this test it could be seen that if an increase in pressure of 55 pounds was developed in three minutes it would require only a short while longer to reach the pressure at which the boiler was tested at the factory when new, which on ordinary tanks would be 200 pounds.

We are told that when water in a copper tank is heated to a temperature of something over 300° F. the efficiency of the material of which it is constructed is reduced about 20 per cent. and, if this is so, the bursting pressure would be reached very quickly. The result of this test plainly demonstrated that the use of pipes made of iron, steel or other ferrous metals is objectionable in many communities as they will fill up in a comparatively few years with rust, scale, etc. and stop up the pipe as effectively as the valve did.

(B) represents a relief valve of the fusible plug type, six inches below the top of boiler, with a combination of pressure, temperature, and vacuum features. When the water in the tank at this level reaches an approximate temperature of 212° F., a fusible plug (consisting of a mixture of tin and bismuth) is melted, providing an opening through which the overheated water can find its way out of the boiler. This at the same time allows an equal quantity of cold water to flow into the boiler, thus chilling it and preventing further trouble from overheating. The objection to this type of valve is that the water will continue to waste out through the opening in the relief valve and drip pipe until someone turns off the supply valve to tank. After this, a new fusible plug must be inserted to replace the one that was melted out.

(C) represents what might be termed a slow acting thermostatic relief valve. It is automatic in operation, opening when the temperature reaches a certain point, about 212° F. After discharging a quantity of hot water and allowing a sufficient quantity of cold water to flow into the boiler to chill it. its thermostatic member will contract and close the valve for another operation. It developed that this valve operated so slowly there was a considerable amount of water and gas utilized between its opening and closing operations, which tended to make it rather wasteful and expensive.

(D) is what might be termed a quick-acting thermostatic type of valve. By this is meant that when the temperature of the water has been increased to the extent that the valve operates, it discharges a quantity of sufficient volume to allow it to close quickly. Thus it decreases the length of time for the gas to burn and allows a smaller quantity of water to be discharged between operations, really making it a desirable and satisfactory valve.

(E and F) are valves of similar construction and were intended for use on the cold water supply pipe to a boiler. One of these, however, was placed on the hot water flow pipe and the other on the cold water supply pipe at about equal distances from the boiler. Neither of these valves operated until temperatures much too high were reached (between 240 and 250° F.). The valve (E) operated first and was allowed to discharge its full maximum through the opened port. At the same time the temperature in the boiler continued to increase, to nearly 245° F. After both valves had operated, it was observed that water at 70° F. continued to flow from valve (E) while the temperature of the water flowing from valve (F) was 240°. This showed that the cold water simply flowed out through the opened relief valve and did not enter the boiler to cool its contents as was intended. During the tests the drip pipes from the various relief valves were all fitted with control valves, so that they could be closed after each relief valve had operated, to allow the temperature to be increased at the location of the next valve about six inches lower down on the boiler.

(11) represents a thermometer placed near the meter and about 15 ft. from the top of the boiler, to check on the temperature of the water in the pipe near the meter when the high temperatures were in the boiler. It developed that when water in the boiler was heated to a temperature of about 212° F. (sometimes much higher) the thermometer near the meter registered about 80° F. which was a safe temperature inasmuch as the meter parts are not damaged until the temperature reaches 90° F. or more.

(10) is a thermometer placed about eight feet away from boiler on the hot water flow line. It was said that hot water would circulate through a pipe this distance and develop a temperature equal to that in the boiler. This did not prove to be the case, however, for the temperature hardly changed, and when the water in the boiler was 240° F. this thermometer did not reach 80° F., thus disproving the circulation theory.

While a great amount of useful data was derived from the tests, the experiments described were the most essential and interesting. Several valves of different types were tested that failed to meet the requirements, and only those that did successfully pass the various tests were approved and are allowed to be used in New Bedford at the present time.

TEN YEARS OF SANITARY IMPROVEMENTS IN RHODE ISLAND PUBLIC WATER SUPPLIES.

BY CHARLES L. POOL[*] AND JAMES J. DILLON.[†]

[*Read September 19, 1935.*]

Ten years ago Stephen DeM. Gage[‡] published a description of public water supplies of Rhode Island in this JOURNAL. The policy of sanitary improvement which he maintained up to 1930 has been continued since with the result that the major sanitary improvements that have taken place make his description obsolete and a revised tabulation necessary. But perhaps the rate of improvement is more important than the present status. The large proportion of supplies showing major sanitary improvements in the past ten years, disregarding supplies[§] for which such improvements have been uncalled for, is evident from the following summary:

Waterworks that have constructed entirely new sources of supply to replace former inferior sources.

Providence.
East Greenwich.

Waterworks that have made material additions to sources of supply.

State College, Kingston.[||]
Block Island.

New water supply systems.

North Tiverton.
Ashaway. (Including chlorination)
Cumberland Hill. (Including chlorination)
Charlestown Beach. (Including chlorination)

Major extensions of distribution systems.

Warwick. (Providence Water Department)
Greenwood.[||] (East Greenwich Water Company)
Bristol County Water Company.

Supplies that have not been previously treated and have adopted chlorination.

Warwick and Coventry.
Oakland Worsted Co.
Pawtuxet Valley.
Harrisville New Village.
Esmond.
Quonochontaug.

Major additions to treatment.

Newport. Ammoniation. Activated carbon. Adjustment of pH. Passage of formerly untreated St. Mary's supply through Newport treatment works.

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[‡] JOURNAL NEW ENGLAND WATER WORKS ASSOCIATION, Vol. 40, No. 2, June 1926, P. 117.

[§] The supplies not pertinent to the summary are 37 small untreated ground water supplies of essentially constant quality, ten of which have been installed within ten years.

[||] P.W.A. Projects.

PUBLIC WATER SUPPLIES

Supply.	Towns and Communities Served.	Date of Installation.	Ownership.	Source.	Drainage Area, Square Miles.
Albion	Albion	1900	Private	2 Drilled wells	—
Alton	Alton	1917	Private	Dug well	—
Andrews	Andrews	1920	Private	Drilled well	—
Ashaway	Ashaway	1928	Private	Drilled well	—
Barrington Beach	Barrington Beach	1903	Private	Drilled well	—
Block Island	Block Island	1888	Private	3 Driven wells and Sands Pond	0.2
Bonnet Shores	Bonnet Shores	1930	Private	Drilled well. Dug well reserve	—
Bradford	Bradford	1913	Private	1 Dug, 10 driven wells	—
Bristol County	Bristol, Warren, Barrington	1887–88	Private	Kickemuit & Palmer Rivers	37.5
Bristol Ferry	Bristol Ferry	1927	Private	Drilled well	—
Charlestown Estates, Inc.	Quonochontaug East Beach	1933	Private	Dug well	—
Common Fence Point	Common Fence Point	1923	Private	2 Dug wells, 2 driven wells	—
Cumberland	Cumberland Hill	1930	Town	Sneech Pond	1
East Greenwich	East Greenwich, Chepiwanoxet, Cowesett, Apponaug, Greenwood	1886	Private	Dug well	—
East Providence	East Providence	1893	Town	Ten Mile River	54
Esmond	Esmond	1907	Private	Dug well	—
Exeter — School	State School	1908	State	11 Driven wells	—
Forestdale	Forestdale	1910	Private	Drilled well	—
Georgiaville	Georgiaville	1910	Private	1 Dug, 1 driven, 1 drilled well	—
Glendale	Glendale	1920	Private	Drilled well	—
Graniteville	Graniteville	1912	Private	Springs and 2 drilled wells	—
Green Hill	Green Hill	1931	Private	Drilled well	—
Greystone	Greystone	1904	Private	Dug well	—
Harris Heights	Harris Heights	1918	Private	Dug well	—
Harrisville New Village	Harrisville New Village	1918	Private	Drilled well	—
Jamestown	Jamestown	1889	Private	2 Ponds	1.2
Kingston	Kingston	1902	Private	Spring and drilled well	—
Kingston State College	State College	1890	State	Dug well & 2 drilled wells reserve	—
Mapleville	Mapleville	1927	Private	Drilled well	—
Mapleville — Pelletier	Mapleville	1921	Private	Drilled well	—
Mapleville — St. Peter	Mapleville	1922	Private	Drilled well	—
Mohegan	Mohegan	1906	Private	3 Drilled wells	—
Narragansett Heights	Narragansett Heights	1926	Private	Dug well	—

of Rhode Island — 1935.

Storage.		Treatment.	Population Served.			Number of Services.	Consumption, Gallons per Day.		Per cent. of Services Metered.
Gallons.	Type.		Permanent.	Summer.	Institutional or Factory.		Summer.	Winter.	
215 000	S. R.	......	1 000	....	700	170	60 000	50 000	0
20 000	E. T.	......	150	....	130	47	7 000		0
90 000	E. T.	......	50	....	....	16	1 000		0
10 000	2 P. T.	Cl.	60	....	85	15	5 000		0
5 000	P. T.	......	....	120	....	25	6 000	0	0
20 000	S. P.	St.	300	1 500	....	60	......	......	0
4 000	P. T.	......	....	340	....	68	......	......	0
20 000	E. T.	......	400	....	600	86	70 000	50 000	0
385 000 000	4 I. R.								
2 450 000	2 S. P.	St.C.S.F.pH.Cl.	24 000	25 400	....	4 089	2.32 m.g.	2.26 m.g.	27.5
7 000	E. T.	......	65	....	....	13	1 800		0
2 500	P. T.	Cl.	....	115	....	23	12 000	0	0
5 000	P. T.	......	....	750	....	150	36 000	0	0
175 000 000	......	St.Cl.	350	....	....	70	30 000	15 000	0
360 000	S. P.								
380 000	S. P.	pH.Cl.	5 000	....	....	1 295	0.46 m.g.		100
420 000 000	I. R.	St.Ae.C.K.S.							
1 000 000	S. P.	A.pH.Cl.F.	18 000	....	....	4 300	1.8 m.g.	1.45 m.g.	98
0	......	Cl.	700	....	800	135	12 000	8 000	0
100 000	E. T.	......	10	....	750	2	20 000	20 000	0
25 000	E. T.	......	175	....	10	26	4 500	3 500	0
40 000	E. T.	Cl.	500	....	....	95	60 000	50 000	0
68 000	2 S. R.	......	45	....	125	10	12 000		0
100 000	2 S. R.	......	750	....	....	124	50 000	40 000	100
600	2 P. T.	......	....	160	....	32	......	......	0
0	......	......	700	....	800	150	43 000		0
10 000	E. T.	......	....	120	....	26	2 500	0	0
50 000	E. T.	Cl.	100	....	....	24	2 000	1 500	100
57 500 000	......								
360 000	S. P.	St.Cl.C.S.F.	1 600	3 200	....	700	0.35 m.g.	0.19 m.g.	1
10 000	E. T.	......	500	....	....	103	12 000	10 000	20
100 000	E. T.	......	60	....	1 100	38	90 000		0
12 000	2 P. T.	......	350	....	300	60	10 000		2
875	P. T.	......	65	....	....	7	1 300	1 100	0
1 500	P. T.	......	60	....	....	13	4 000		0
16 500	S. R.	......	225	....	150	48	9 500		0
1 500	T.	......	....	120	....	27	2 000	0	0

PUBLIC WATER SUPPLIES

Supply.	Towns and Communities Served.	Date of Installation.	Ownership.	Source.	Drainage Area, Square Miles.
Newport	Newport, Middletown	1876	Private	Ponds	7.9
Nasonville	Nasonville	1926	Private	Drilled well	—
North Scituate	North Scituate	1927	Private	Dug well	—
North Tiverton	North Tiverton	1928	District	30 Driven wells	—
Oakland, Worsted Co.	Oakland	1895	Private	2 Drilled wells	—
Oakland, Remington	Oakland	1898	Private	2 Dug wells	—
Pascoag	Pascoag, Harrisville, Bridgeton	1903	Private	Brook, dug and collecting wells	0.6
Pawtucket	Pawtucket, Central Falls, Parts of Cumberland, Lincoln, East and North Providence	1878	City	Abbott Run	27.8
Pawtuxet Valley	Parts of West Warwick, Coventry, Cranston, Scituate and Warwick	1887	Private	2 Impounding reservoirs	1.6
Providence	Providence, Cranston and parts of Warwick, Johnston and North Providence	1870	City	Impounded reservoirs	92.8
Prudence Island	Prudence Island	1905	Private	Springy area	—
Quonochontaug	Quonochontaug Central Beach	1926	Private	Dug well	—
Saunderstown	Saunderstown	1930	Private	Drilled well	—
Seaconnet	Sakonnet Beach	1913	Private	Dug well	—
Slatersville	Slatersville	1918	Private	Branch River	90
South Warren, Scott	South Warren	—	Private	Dug well	—
South Warren, Greene	South Warren	1910	Private	Drilled well	—
Stillwater	Stillwater	1875	Private	Spring	—
Swift's Point	Swift's Point	1929	Private	Driven well	—
Touisset	Touisset	1920	Private	2 Dug wells	—
Touisset Highlands	Touisset Highlands	1926	Private	Drilled well	—
Touisset Point	Touisset Point	1912	Private	Drilled well	—
Wakefield	Wakefield, Peacedale, Rocky Brook, Narragansett Pier	1889	Private	Rocky Brook	2
Wallum Lake	State Sanatorium	1905	State	Wallum Lake	2.4
Warwick & Coventry	West Warwick, Coventry	1890	Private	Carr's Pond	0.6
Wesquage, Bennett	Wesquage	1905	Private	Spring	—
Wesquage, Gilbert	Lot 23, Jenks Farm	1925	Private	Drilled well	—
Wesquage, Johnson	Wesquage	1927	Private	Drilled well	—
Westerly	Westerly; Pawcatuck, Conn.	1886	Town	133 Driven wells	—
Woonsocket	Woonsocket, North Smithfield, Manville; Blackstone, Mass., Bellingham, Mass.	1884	City	Impounded reservoirs	8.5

Storage. S.R. — Storage reservoir; I.R. — Impounding reservoir; E.T. — Elevated tank; P.T. — Pressure tank; S.P. — Standpipe.

of Rhode Island — 1935—Concluded.

Storage.		Treatment.	Population Served.			Number of Services.	Consumption, Gallons per Day.		Per cent. of Services Metered.
Gallons.	Type.		Permanent.	Summer.	Institutional or Factory.		Summer.	Winter.	
1 583 000 000	......	St.A.C.K.Ae.							
8 000 000	S. R.	S.Cl.F.Cl.pH.	27 900	....	....	....	4.25 m.g.	3.64 m.g.	33.3
0	......	......	40	....	....	12	......	......	0
1 000	P. T.	......	25	....	....	8	......	......	0
1 050 000	S. R.	......	2 400	....	....	325	70 000	60 000	100
15 000	T.	Cl.	600	....	200	120	15 000		0
5 500	E. T.	......	150	....	....	29	1 500		0
235 000	S. P.	Cl.	5 000	....	....	700	150 000		100
2 764 000 000	2 I. R.								
20 000 000	S. R.	St.Cl.	130 350	....	....	18 069	9.4 m.g.	9.0 m.g.	100
285 000 000	2 I. R.	St.Cl.	8 000	....	....	1 571	0.7 m.g.	0.4 m.g.	100
	I. R. &								97
40 515 000 000	Ponds	St.C.Ae.pH.S.F.Ae.,							(ex. War
57 000 000	2 S. R.	Cl. when needed	336 900	....	....	45 600	29 m.g.	26 m.g.	87)
20 000	E. T.	......	....	750	....	180	......	......	0
2 500	P. T.	Cl.	....	180	....	36	29 000	0	0
1 000	P. T.	......	....	85	....	15	10 000	0	0
10 000	P. T.	......	....	200	....	....	......	......	..
400 000 000	I. R.						100 000		
25 000	E. T.	St.C.pH.S.F.Cl.	....	350	....	68	(mill-use included)		0
500	E. T.	......	....	35	....	8	300	0	0
5 000	T.	......	40	47	24	17	5 000	4 000	0
750	E. T.	......	100	....	275	20	......	......	0
1 000	E. T.	......	....	40	....	10	4 000	0	..
9 000	3 P. T.	......	3	400	....	70	36 000	150	0
2 000	P. T.	......	....	100	....	24	3 000	0	0
900	P. T.	......	2	27	....	10	2 700	150	0
53 500 000	3 I. R.								
370 000	S. P.	St.C.S.pH.Cl.F.	4 000	7 000	....	1 370	0.7 m.g.	0.3 m.g.	60
50 000	E. T.	St.Cl.	130	....	650	9	0.17 m.g.	0.14 m.g.	0
400 000 000	......								
475 000	S. P.	St.Cl.	12 000	....	....	2 400	0.9 m.g.	0.6 m.g.	100
500	P. T.	......	10	50	....	7	12 000	1 000	0
1 000	P. T.	......	....	50	....	10	2 300	0	0
10 000	S. R.	......	....	65	....	13	5 000	0	0
1 500 000	2 S. P.								
	1 E. T.	......	16 500	23 500	....	3 536	1.46 m.g.	0.85 m.g.	94
1 135 000 000	I. R.								
5 500 000	5 S. P.	St.Cl.	58 000	....	....	7 100	3.0 m.g.		100

Treatment. A. — Ammoniation; Ae. — Aëration; Cl. — Chlorination; C. — Coagulation; F. — Filtration; K. — Activated carbon; pH. — Correction of Reaction; S. — Sedimentation; St. — Storage of Protective Significance.

East Providence. Storage*. Aëration*. Ammoniation. Activated carbon. Adjustment of pH.

Wakefield. Coagulation. Filtration. Adjustment of pH.

East Greenwich. Adjustment of pH.

Miscellaneous.

Providence. Major improvements to watershed and distribution system.

Woonsocket. Correction of large majority of cross-connection hazards.

Our program of elimination of hazardous cross-connections with polluted fire or industrial supplies has not been confined to Woonsocket; some 100 connections have been eliminated or provided with approved double check valves in the past three years.

Waterworks that have not had need of major sanitary improvement.

Westerly. Excellent supply but adjustment of pH recommended.

Wallum Lake.

Georgiaville.

Jamestown.

Waterworks for which major sanitary improvements are desirable.

Pawtucket. Filtration plant desirable.

Pascoag and Harrisville. Inadequate.

Slatersville. Storage needed to make cross-connection elimination feasible.

These three are not the only supplies for which improvements or additions are desirable. A few of the 19 supplies that have undergone major improvements still need others.

A milestone was reached when the provision of wells late in 1935 for Block Island's source of supply removed the last untreated surface water supply in the state from regular use. If enough ground water cannot be obtained, the pond now available for auxiliary summer supply will require chlorination.

The improvements are reflected in improved bacteriological quality, the mean for all supplies now showing but 5 per cent. of samples to contain *Bact. coli* in 10-cc. portions over a considerable period of time, as compared with the time-honored standard of the U. S. Public Health Service to the effect that not over 10 per cent. of such portions should contain *Bact. coli* for any supply. It is planned to apply to the supplies the Chase scoring system the application of which A. D. Weston† has described for ten Massachusetts supplies.

The best available statistics and estimates are summarized in the preceding table from which it is calculated that a resident population totaling 657 715 is served by public water supplies, or 94 per cent. of the present population of the state according to our estimate.

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*P. W. A. Projects.

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PUBLIC GROUND WATER SUPPLIES IN MASSACHUSETTS.

BY FRANCIS H. KINGSBURY.*

[*Read September 19, 1935.*]

Water supplies are commonly classified as surface water supplies or ground water supplies. Surface water, as the name implies, runs off the ground to be collected in streams, ponds or reservoirs. Ground water, first surface water, passes through the soil in its path towards the lowest possible level and may reappear at the surface in the form of springs or may rest in underground reservoirs or streams until tapped by means of wells or other forms of collecting works. The water in underground storage is seldom stationary and generally moves slowly towards lower levels.

The population of Massachusetts according to the 1930 census was 4 249 614, of which 4 129 000 people or 97.2 per cent. were served by public water supplies.

The Boston Metropolitan Water District and many of the larger cities outside of the district, comprising a total population of 3 170 000 inhabitants, are furnished wholly with surface water either with or without treatment. There are in Massachusetts, however, 129 municipalities supplied in whole or in part from ground water sources. The population of 958 000 thus supplied fully justifies devoting time to a review of past experiences in developing ground water supplies in order better to cope with present problems.

Ground Water Works in Massachusetts. Information as to the types of works used for collecting ground water since public supplies were first introduced is scattered through many volumes of official reports or is hidden in the files of engineers, some of whom have long since passed on. In order that a portion at least of this valuable information may be made readily available for the benefit of water works officials and engineers, a tabulation of such facts as could be collected without recourse to the over-worked questionnaire is herein presented. The mass of data collected is sufficient to permit the perception of certain trends in the art of developing ground water sources and to show why some forms of installations failed while others succeeded. The accompanying table is presented for convenience in tracing the works in use by each municipality in Massachusetts which has been supplied with water from ground water sources.

One of the first questions that will probably be asked is where these supplies are located with reference to the geographical boundaries of the

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*Massachusetts Department of Health, Boston, Mass.

TYPES OF GROUND WATER SUPPLIES

MUNICIPALITY AND OWNER OF SOURCE OF SUPPLY	Prior to 1870.	1871–1880.	1881–1890.	1891–1900.
ACTON West and South Water Supply District.	....	....	....	....
ADAMS Adams Fire District.	....	*1874* Reservoir (surface).	Well (Renfrew).	*1895* Tubular wells (Zylonite).
AGAWAM 1877 C. L. Goodhue. 1905 Town.	....	*1877* Spring.	....	....
AMESBURY 1885 Powow Hill Water Co. 1906 Town.	....	....	*1885* Tubular wells; 36 abandoned. Open basin 80′x40′x14′. Tubular wells in bottom; 14′–20′ deep.	Open Basin, 100′x50′x15′. Tubular wells in bottom; 12′–3″x100′. Tubular wells; 6–85′–125′. Dug well, 18′ dia.x45′ with 16″x200′ well in bottom. *1897* Tubular wells; 3–8″x200′ abandoned.
AMHERST 1887 Spring Water Co. 1880 Amherst Water Co.	....	*1880* Surface water supply.	*1887* Springs or wells; 7 to reservoir, 70′x40′x6′.	....
ARLINGTON 1872 Town. 1899 Metropolitan.	....	*1872* Surface reservoir (complaints). *1876–1877* Filter gallery.	*1883* Addition to filter gallery. Total length 858′.	*1895* High service supply. Tubular wells; 25–2½″x35′ Av. *1899* Low service Metropolitan.
ASHFIELD Water Company.	Springs many years prior to 1875.	....	....	....
ASHLAND 1911 Town.	....	....	....	....
ATTLEBORO 1873 Attleboro Water Supply District. 1892 Town.	....	*1873* Dug well; 13′ dia. 3 tubular wells in bottom.	*1882* Filter gallery; 5 tubular wells in bottom.	*1892* Old supply abandoned. New dug well; 30′ dia.x25′. Tubular well in bottom; 1¼″x25′.
AUBURN Auburn Water Co.	....	....	....	....
AVON Town.	....	....	*1890* Dug well; 20′ dia.x22′.	....
AYER Town.	....	....	*1887* Dug well; 25′dia.x18′.	....
BARNSTABLE (Hyannis) Barnstable Water Co.	....	....	....	....

AND DATES OF INSTALLATION.

1901–1910.	1911–1920.	1921–1930.	Since 1930.	In Use, 1935.
....	*1912* Tubular wells; 20–2½″x18′–41′.	....	....	Tubular wells; 20–2½″x18′–41′.
1902 Tubular wells; 6–6″x106′.	....	....	....	Reservoirs (surface). Tubular wells; 6–6″x106′.
1905 Surface supply from West Springfield.	*1912 and 1915* Surface supply from Springfield.	....	....	Surface water supply.
....	*1911* Tubular wells; 30–2½″x30′–60′. *1914* 15–2½″x30′–60′.	*1923* Tubular wells; 12–2½″x30′–60′. *1927* 47–2½″x25′–55′. Iron removal plant.	....	Tubular wells; 103–2½″x25′–60′. Iron removal plant.
....	....	....	....	Surface water supply.
....	....	....	....	Surface water supply.
....	....	....	....	Surface water supply.
....	*1911* Tubular wells; 12–2½″x25′–32′. *1919* 7–2½″x28′–35′.	....	....	Tubular wells; 11–2½″x25′–35′.
1904 Dug well; 40′ dia.x25′. Filter conduit 250′. *1907* Charging filter. *1910* Reservoir for charging water.	....	*1929* Tubular wells; 88–2½″x18′–30′.	*1935* Gravel packed well. 1–18″ dia.x35′. 1–36″ dia.x35′.	Dug wells; 1–30′ dia.x25′, 1–40′ dia.x25′, with charging filter and reservoir. Tubular wells; 88–2½″x18′–30′.
....	*1920* Tubular wells; 9–2½′x19′–43′.	Dug wells; 4–6′–10′ dia.x12′–30′. *1930* Tubular well; 2½″x19′.	....	Tubular wells; 9–2½″x19′–43′. Dug wells; 4–6′–10′ dia.x12′–19′. Tubular well; 2½″x19′.
1907–1908 Drilled wells; 1–8″x201′, 1–8″x225′.	....	....	....	Dug well; 20′ dia.x22′. Drilled wells; 2–8″x201′ and 225′.
1906 Tubular wells; 30–2½″ and 2″x25′–40′.	....	....	....	Dug well; 25′ dia.x18′. Tubular wells; 25–2½″x25′–40′.
....	*1912* Dug wells; 24–24″ dia.x25′–35′.	*1925* Tubular wells; 26–2½″x30′ Av. *1926* Tubular wells; 35–2½″x25′–35′, 33–2½″x18′–37′.	....	Tubular wells; 54–2½″x18′–37′, 35–2½″x25′–35′. Dug wells; 24–24″x25′–35′.

Types of Ground Water Supplies

Municipality and Owner of Source of Supply.	Prior to 1870.	1871–1880.	1881–1890.	1891–1900.
Barnstable (West Barnstable) Barnstable Water District.	....	....	....	....
Bedford Town.	....	....	....	....
Belchertown Belchertown Water District.	....	....	....	....
Belmont 1887 Watertown Water Co. 1898 Metropolitan.	....	....	*1887* See Watertown Water Co.	*1898* Metropolitan.
Billerica Town.	....	....	....	*1899* Tubular wells; 35-2½″x15′-41′.
Bourne Monument Beach Water Co.	....	....	....	....
Sagamore Keith Car Works.	....	....	....	....
Sagamore Beach	....	....	....	....
Sagamore Heights	....	....	....	....
Pocasset Beach	....	....	....	....
North Shore	....	....	....	....
Bradford (now a part of Haverhill) 1886 Bradford Water Co. 1895 Town. 1897 Annexed to Haverhill.	....	....	*1890* Dug wells; 3–12′x12′x20′, 4–12′x24′x20′, 1–12′x24′x30′.	*1891* Dug wells; 1–12′x24′x18, 1–24′x24′x18′, 1–23′x23′x22′. *1892* Dug wells; 2—similar abandoned. *1896* Haverhill surface supply.
Braintree 1887 Braintree Water Supply Co. 1891 Town.	....	....	*1887* Filter gallery; 112′x15′x13½′.	*1893* Connection to pond. *1897* Tubular wells; 9–6″x22′–25′.
Bridgewater 1888 Bridgewater Water Co. 1925 Town.	....	....	*1888* Dug wells; 1–45′ dia.x18′, 1–18′ dia.x18′. *1889* Dug well; 10′ dia. x 27′ with 6″x86½′ tubular well in bottom. Drilled well; 6″x202′.	*1892* Drilled wells; 5–6″x100′–160′. *1895* Drilled wells; 9–6″x95′–165′.
Brockton City.	....	*1880* Drains. 1½ acres of 4″ drains 8′ apart under reservoir (never used).	....	....
Brookfield Town.	....	....	*1889* Reservoir (surface).	....

AND DATES OF INSTALLATION—*Continued.*

1901–1910.	1911–1920.	1921–1930.	Since 1930.	In Use, 1935.
....	....	....	*1934* Supplied from Yarmouth.	Supplied from Yarmouth by tubular wells.
1909 Dug well; 20′ dia.x21′. Charging filter.	....	*1925* Tubular wells; 10–2½″x30′–35′. *1930* 20–2½″x30′–35′	....	Dug well and charging filter; 20′ dia.x21′. Tubular wells; 30–2½″x30′–35′.
....	....	*1925* Tubular wells; 9–2½″x31′–37′.	....	Tubular wells; 9–2½″x31′–37′.
....	....	....	....	Surface water supply.
....	*1916–1924* Tubular wells; 75–2½″x28′–30′.	....	*1932* Gravel packed wells; 2–18″dia.x37′ and 38′.	Gravel packed wells and aerator with settling tank. 2 wells; 18″ dia.x37′ and 38′.
....	*1916* Tubular wells.	*1927* Tubular wells; 6–2″x16′.	....	Tubular wells; 6–2″x16′.
1909 Six small systems. 2–4 wells each. Tubular wells.	....	....	....	Tubular wells; Six small systems.
....	....	....	....	Spring; 40′x10′x12′. Tubular wells; 7–2½″.
....	....	....	....	Tubular well; 2½″x90′.
....	....	*1923* Tubular wells; 3–2″x90′.	....	Tubular wells; 3–2″x90′.
....	....	*1926* Tubular wells; 2–1½″x12′.	....	Tubular wells; 2–1½″x12′.
....	....	....	....	Surface water supply. (Part of Haverhill.)
Old supply. Abandoned from domestic use.	*1912* Surface water supply.	....	....	Surface water supply.
1906 Drilled well; 8″x237′. Abandoned.	*1912* Tubular wells; 108–2½″x30′–45′. (Abandoned later.) *1920* 24–2½″x35′–59′.	*1925* 10–2½″x35′–59′.	*1934* Wells redriven.	Tubular wells; 31–2½″x28′–57′.
....	....	....	....	Surface water supply.
....	*1912–1915* 3 Dug wells with wood plank sides. 3–10′–13′x12′–13½′x10′–15′.	*1930* Dug wells; reconstructed. *1930* Tubular wells; 14–2½″x13′–15′.	....	Dug wells;(gravel packed) 3–48″ dia.x12′. Tubular wells; 14–2½″x13′–15′. Surface water supply also.

TYPES OF GROUND WATER SUPPLIES

Municipality and Owner of Source of Supply.	Prior to 1870.	1871–1880.	1881–1890.	1891–1900.
Brookline Town. Joined Metropolitan in 1925.	....	*1875* Filter gallery; 1062′x4′ and 6′x2′ and 6′, charging ditch. *1879* Gallery extended 160′.	*1883* Gallery extended 220′; total length 1442′.	*1891* Tubular wells; 44–2½″x16′–67′ (gravity flow at first). *1893–1894* 134–2½″x35′–95′. *1895* 13–2½″.
Cambridge 1806 Cambridgeport Aqueduct Co. 1856 City.	*1806* Springs. *1837* Springs. *1856* Pond.	*1876* Filter gallery.	*1887* Reservoirs (surface).	....
Canton Town.	....	....	*1889* Dug well; 40′ dia.x20′. Tubular wells, 10 used to unwater excavation.	*1893* Tubular wells; 19–2½″x20′–40′. *1894* Dug well; 40′ dia.x 23′ gravity flow.
Chatham Chatham Water Co.	....	....	....	....
Chelmsford North Chelmsford Fire District.	....	....	....	....
Chelmsford Water District.	....	....	....	....
Cheshire Cheshire Water Co.	....	*1876* Springs in reservoir; 200′x66′x10′.	Surface water supply later.	....
Chicopee Chicopee Mfg. Co. 1892 City.	Springs in reservoir; 30′x20′x2′.	....	....	*1892* Taken over by city. *1893* Surface water supply.
Chicopee Water Co. 1892 City.	*1830* Springs. *1845* Dug wells; 6–4′x4′–12′x 12′x10′–12′, deep.			
Cohasset Cohasset Water Co.	....	....	*1886* Tubular wells; 63–2″x25′–40′. *1887* 7–2½″x20′–38′.	....
Colrain Griswoldville Mfg. Co.	....	....	....	....
Cummington Town.	....	....	....	Spring; 4′x12′x3′.
Danvers 1796 Salem Aqueduct Co. 1876 Town.	*1796–1839* Springs.	*1876* Surface water supply only.		
Dedham Dedham Water Co.	....	....	*1881* Dug wells; 1–26′ dia.x18′, 1–8′ dia.x18′.	*1897* Tubular wells; 5–4″ in bottom of large dug well. *1899* 6′ dia.x35′; near large dug well.

and Dates of Installation—*Continued.*

1901–1910.	1911–1920.	1921–1930.	Since 1930.	In Use, 1935.
....	*1911* Gallery extended. 4′x6′x450′. Charging basins. *1918* Iron and manganese removal plant.	*1925* Metropolitan supply also.	....	Filter gallery; 4′ and 6′x2′ and 6′x1442′. Charging filters. Tubular wells: 2½″x16′–95′. Iron and manganese removal plant. Metropolitan supply.
....	....	....	....	Surface water supply.
....	....	*1927* Dug well; 35′ dia.x25′.	....	Dug wells; 1–40′ dia.x20′, 1–40′ dia.x25′, 1–35′ dia.x25′. Charging filters planned. Tubular wells; 19–2½″x20′–40′.
....	....	*1929* Filter gallery; 5′x10′x114′. Filter crib under pond: 10′x10′x25′.	*1933* Tubular wells; 25–2½″x35′ Av. *1935* 14–2½″x33′–36′.	Tubular wells; 38–2½″x30′–36′.
1907 Tubular wells; 10–2½″x23′–30′. *1908* 10–2½″x20′–35′.	....	*1922* Tubular wells; 10–2½″x21′–30′.	....	Tubular wells; 30–2½″x20′–35′.
....	*1913* Tubular wells; 15–2½″x28′–42′.	....	....	Tubular wells; 15–2½″x28′–42′.
....	....	....	....	Surface water supply.
....	....	....	....	Surface water supply.
1902 Filter gallery; 200′x7′x12′. *1908* Dug well; 25′ dia.x25′. Charging filters.	*1913* Iron removal plant.	....	....	Tubular wells; 6–2½″x20′–38′. Dug well; 25′ dia.x25′. Charging filters. Iron removal plant.
....	....	....	....	Drilled well; 10″x291′.
....	*1916* Tubular wells; 3–6″x25′. Dug well; 10′ dia.x7′, with 6″ well in bottom.	....	....	Spring; 4′x12′x3′.
....	....	....	....	Surface water supply.
1901 Tubular wells; 21–4″x30′–32′. *1904–1905* 8–4″x30′–32′.	*1913* Caisson well; 16″ dia.x60′. *1914* 4″x20′ in dug well. *1915* 4–8″x35′.	Small dug well abandoned.	*1935* Tubular wells; 8–2½″x29′–33′.	Tubular wells; 33–4″x30′–32′, 4–8″x35′. Dug wells; 1–16″ dia.x60′, 1–26′ dia.x18′, with 4″ wells in bottom Tubular wells; 8–2½″x29′–33′.

TYPES OF GROUND WATER SUPPLIES

MUNICIPALITY AND OWNER OF SOURCE OF SUPPLY.	Prior to 1870.	1871–1880.	1881–1890.	1891–1900.
DEERFIELD Deerfield Fire District.	....	....	....	....
DOUGLAS Town.	....	....	....	....
DRACUT (Collinsville) 1900 American Woolen Co. 1934 Dracut Water Supply District.	....	....	....	*1900* Tubular wells; 8–2½″x Av. 22′. Gravity to Pumping Station.
(Dracut Centre) 1906 Dracut Water Supply District.	....	....	....	....
DUDLEY Town.	....	....	....	....
DUNSTABLE Town.	....	....	....	....
DUXBURY Duxbury Fire and Water District.	....	....	....	....
EAST BRIDGEWATER 1888 Bridgewater Water Co. 1908 Town.	....	....	*1888* Supply from Bridgewater Water Co. Ground water (see Bridgewater).	....
EAST BROOKFIELD 1909 Part of Brookfield. 1920 Town.	....	....	....	....
EASTHAMPTON Town.	*1870* Reservoir and pond.	....	....	....
EASTON North Easton Village District. Unionville Fire and Water District. (Same supply.)	....	....	*1887* Dug well; 27′ dia.x28′. Spring. Reservoir with underdrains 5′ under ground (never used).	....
EDGARTOWN Edgartown Water Co.	....	....	....	....
FAIRHAVEN Fairhaven Water Co.	....	....	....	*1894* Tubular wells; 26–2½″x35′ Av. *1899–1900* 46–2½″x35′ Av. *1900* 31–2½″x35′ Av. (summer only).
FALMOUTH 1893 Falmouth Heights Water Co. 1899 Falmouth Water Co. 1902 Town.	....	....	....	*1893* Dug well; 10′ dia.x20′. *1899* Tubular wells; 15–2½″x45′ Av. (never used). Surface supply.

and Dates of Installation—*Continued.*

1901–1910.	1911–1920.	1921–1930.	Since 1930.	In Use, 1935.
....	*1911* Springs; 1–12′ dia.x12′, 1–6′ dia.x8′. Dug well; 25′ dia.x15′. *1915* Springs collected by drains.	*1930* Tubular wells; 8–2½″x15′.	*1935* Spring by collecting drains.	Springs; 1–12′ dia.x12′, 1–6′ dia.x8′. Large well; 25′ dia.x15′. Springs and collecting drains.
1910 Tubular wells; 8–2½″x23′–34′.	....	....	....	Tubular wells; 8–2½″x23′–34′.
....	....	....	*1933 and 1934* Tubuar wells; 12–2½″x22′ Av. Dug wells; 2–4′ dia.x18′.	Tubular wells; 20–2½″x22′ Av. Dug well; 4′ dia.x18′.
1906 Tubular wells; 10–2½″x20′–30′. *1908* 1–8″x32′.	....	*1922* Tubular wells; 16–2½″x18′–34½′. Dug well; 4½′ dia.x50′. *1929–1930* Dug wells; 14–48″ dia.x24′.	*1932* Dug wells; 1–60″x24′, 1–48″x24′. *1934* Tubular wells; 7–2½″x23′–29′.	Dug wells; 1–4½′ dia.x24′, 16–42″, 48″ and 60″ dia.x24′. Tubular wells; 7–2½″x23′–29′.
1910 Tubular wells; 7–2½″x30′–40′.	Tubular wells; 4–2½″x30′–40′.	*1929* Tubular wells; 6–2½″x25′–28½′, 6–2½″ later.	....	Tubular wells; 23–2½″x25′–40′.
....	*1918* Dug well; 12′ dia.x30′.	*1929–1930* Tubular wells; 4–2½″x19′–23′.	....	Dug well; 12′ dia.x18′. Tubular wells; 4–2½″x19′–23′.
....	*1914* Tubular wells; 22–2½″x26′–37′.	*1926* Tubular wells; 22–2½″x29′–49′.	....	Tubular wells; 44–2½″x26′–49′.
1908 Surface supply from Brockton.	....	....	....	Surface water supply.
1909 Dug well; 22½′ dia.x15′. Tubular wells; 12–2½″x19′–24′. Abandoned.	....	*1923* Collecting drain 200′.	....	Dug well; 22½′ dia.x15′. Collecting drain 200′.
1909 Tubular wells; 27–2½″x35′–40′.	....	*1924* Tubular wells; 10–4″x30′–54′.	....	Tubular wells; 27–2½″x35′–40′, 10–4″x30′–54′.
....	....	....	....	Dug well; 27′ dia.x28′. Spring. Reservoir (charging).
1906 Tubular test wells. Dug well; 15′ dia.x19′.	....	*1927* Tubular wells; 17–2½″x35′ Av.	....	Dug well; 15′ dia.x19′. Tubular wells; 17–2½″x35′ Av.
1910 1–2½″x20′.	....	....	....	Tubular wells; 22–2½″x25′–35′, 31–2½″x30′ Av., 1–2½″x20′ (auxiliary).
....	....	....	....	Surface water supply.

TYPES OF GROUND WATER SUPPLIES

MUNICIPALITY AND OWNER OF SOURCE OF SUPPLY.	Prior to 1870.	1871–1880.	1881–1890.	1891–1900.
FOXBOROUGH 1891 Foxborough Water Supply District. 1931 Town.	....	....	....	*1891* Tubular wells; 24-2″x30′-56′.
FRAMINGHAM 1885 Framingham Water Co. 1905 Town.	....	....	*1885* Filter galleries; 4′x4′x200′ and 250′, partly under pond. Also surface supply from Boston Water Works.	....
FRANKLIN 1884 Franklin Water Co. 1907 Town.	....	....	*1884* Dug well; 20′ dia.x25′. *1887* Dug well; 30′ dia.x18′.	Pond also.
GEORGETOWN Town.	....	....	....	....
GILL Riverside Water Co.	....	....	*1888* Springs, 1—enclosed, 1—open.	
GRAFTON 1845 Grafton Aqueduct Co. 1886 Grafton Water Co.	*1845* Springs.	....	*1886* Spring and collecting gallery; 95′x12′x17′. *1889* Drilled well; 6″x97′.	*1893* Springs (Saundersville).
GRANVILLE Granville Center Water Co.	....	....	....	....
GREAT BARRINGTON Great Barrington Water Co. 1892 Great Barrington Fire District.	*1867* Reservoir (surface).	....	....	....
GREENFIELD 1870 Greenfield Fire District. Town.	*1870* Reservoirs (surface).	....	....	....
GROTON Groton Water Co.	....	....	....	*1897* Dug well; 30′ dia.x16′.
West Groton Water Supply District.	....	....	....	....
HANOVER Town.	....	....	....	....
HARDWICK G. H. Gilbert Co. (Gilbertville).	....	....	*1887* Dug well.	....
Geo. W. Wheelwright Paper Co. (Wheelwright).	....	....	....	....
Hardwick Village	....	....	....	....

AND DATES OF INSTALLATION—*Continued.*

1901–1910.	1911–1920.	1921–1930.	Since 1930.	In Use, 1935.
....	....	*1922* Tubular wells; 23–2½″x28′–50′. *1929–1930* 10–2½″x30′ Av.	....	Tubular wells; 33–2½″x28′–50′.
....	....	....	....	Filter galleries; 4′x4′x200′ and 250′. Surface water supply also Metropolitan.
1910 Tubular wells; 20–2½″x20′.	....	*1924–1925* Small dug wells; 11–24″x about 20′, 1–36″x about 20′. *1929* 6–30″x about 20′.	....	Large dug well; 20′ dia.x25′. Tubular wells; 8–2½″x20′. Small dug wells; 11–24″x about 20′, 1–36″x about 20′, 6–30″x about 20′.
....	....	....	*1934* Tubular wells; 19–2½″x25′–38′. Iron removal plant.	Tubular wells; 19–2½″x25′–38′. Iron and CO_2 removal plant.
....	....	....	....	Springs; 1—enclosed, 1—open.
1910 Dug well; 25′ dia.x28′.	....	*1930* Gravel packed well; 16″x38′.	....	Dug wells; 1–95′x12′x17′, 1–25′ dia.x28′. Gravel packed well; 16″x38′.
1910 Dug well; 32′ dia.x11½′. Springs or wells; 1–10′x12′x8′, 1–8–x10–x8½′.	....	....	....	Dug well; 32′ dia.x11½′. Springs or wells; 1–10′x12′x8′, 1–8′x10′x8½′ (gravity flow).
1909 Dug well and filter crib; 12′x14′x10′.	*1913* Dug well; 15′x15′x10′.	....	*1934* Infiltration gallery; 4′x6′x225′.	Infiltration gallery; 4′x6′x225′. Surface water supply.
....	*1913* Dug well; 40′ dia.x27′. Charging filter ¾ acre and drains.	....	....	Surface water supply. Dug well; 40′ dia.x27′. Charging filter and drains.
....	....	....	....	Dug well; 30′ dia.x16′.
....	*1912* Tubular wells; 8–2½″x25′–28′.	....	....	Tubular wells; 8–2½″x25′–28′.
....	....	*1930* Tubular wells; 24–2½″x38′–48′.	....	Tubular wells; 24–2½″x38′–48′.
....	*1911* Drilled wells; 1–6″x129′, 1–6″x197′.	*1922* Drilled wells; 2–10″x225′ and 233′. Springs or wells; 1–21 dia.x15′, 2–39 dia.x14½′, 1–10′x20′x9½′, 1–8′x15′x9′.	....	Drilled wells; 2–6″ and 2–10″x129′–233′. Dug wells or springs; 1–21′ dia.x15′, 2–39′ dia.x14½′, 1–10′x20′x9½′, 1–8′x15′x9′.
1904–1908 Tubular wells; 3–2½″x29′–35′.	....	*1924* Tubular wells; 2½″.	....	Tubular wells; 4–2½″x29′–35′.
....	*1913* Dug well; 24′x12′x10′.	....	....	Dug well; 24′x12′x10′.

TYPES OF GROUND WATER SUPPLIES

MUNICIPALITY AND OWNER OF SOURCE OF SUPPLY.	Prior to 1870.	1871–1880.	1881–1890.	1891–1900.
Hingham Hingham Water Co.	....	*1880* Pond.	....	....
Holliston Holliston Water Co.	....	....	....	*1891* Dug well; 26′ dia.x30′, lower 10′ in ledge. Charging reservoir and crib.
Hopkinton Town.	Spring at private factory. (100 families.)	....	*1884* Drilled wells; 3–4″x85′–92½′ (top of hill). *1889* 1–8″x119′.	....
Huntington Huntington Fire District.	....	....	*1889* Reservoir (surface).	....
Hyde Park (now part of Boston) Hyde Park Water Co.	....	....	*1885* Tubular wells; 64–2″x34′–38′.	*1892* Dug well. *1893* Tubular wells; 33–2½″x25′–28′ (12 old wells abandoned). *1894* 6–6″x40′ Av. *1900* 21–2½″x30′ Av.
Kingston Kingston Aqueduct Co. 1886 Town.	Springs.	....	*1886* Dug well; 20′ dia.x18′. *1888* Filter gallery; 360′x20″x14″.	*1891* Filter gallery; 1200′x20″x18″. *1897* Tubular wells; 24–2½″x23′–44′.
Lancaster 1797 Lancaster Aqueduct Co. 1871 Union Aqueduct Co. 1885 Town.	Springs.	....	*1885* Surface water supply.	....
Lawrence City.	....	*1875* Filter gallery; 300′x8′x8′ and river direct.	....	*1893* River water filtered.
Leicester Leicester Water Supply District.	....	....	....	*1891* Dug wells; 7–6′–7′ dia.x8′–12′, 1–30′ dia.x12′. (Gravity flow.)
Cherry Valley and Rochdale Water District.	....	....	....	....
Lexington 1884 Lexington Water Co. 1895 Town. 1903 Metropolitan.	....	....	*1881* Springs. *1884* Dug wells; 1–20′ dia.x19′, 1–20′ dia.x18′. 200′ of collecting drain.	*1891* Dug wells; 1–12′ dia.x11′, 1–10′ dia.x11′. Drilled well; 8″x190′. *1892* Filter gallery; 70′x6′x6′ with tubular wells in bottom. *1894* Additional ground water. *1897* Reservoir (surface).
Littleton Town.	....	....	....	....

AND DATES OF INSTALLATION—*Continued.*

1901–1910.	1911–1920.	1921–1930.	Since 1930.	In Use, 1935.
1903 Dug well; 40′ dia.x20′. Collecting drains with open joints; 1440′x8″–15″. Charging basins.	*1912* Surface water supply.	....	....	Surface water supply. Dug well; 40′ dia.x20′, with collecting drains; 1440′x8″–15″ and charging basins.
Filter basin; 100′x125′x4′, constructed from old crib.	....	....	....	Dug well; 26′ dia.x30′. Filter basin; 100′x125′x4′.
....	....	*1929–1930* Tubular wells; 25–2½″x27′–41′.	....	Tubular wells; 25–2½″x27′–41′.
1908 Tubular wells; 9–2½″x19′–37′.	....	....	....	Surface water supply. Tubular wells; 9–2½″x19′–37′.
....	....	....	....	Part of Boston Metropolitan supply.
....	....	*1922* Tubular wells; 7–2½″x20′–40′.	....	Tubular wells; 31–2½″x20′–44′. Dug well used as pump well.
....	....	....	....	Surface water supply. Study being made for tubular well supply.
....	....	....	....	Surface water supply. Filtered.
....	....	*1924* Drilled well; 8″x146′.	....	Dug wells (gravity); 7–6′–7′ dia.x8′–12′. Drilled well (pumped); 8″x146′. Dug well; 30′ dia.x12′.
....	*1911* Dug wells; 2–30′ dia.x12′. Filter; 50′x8′x8′, for surface water.	....	....	Dug wells; 2–30′ dia.x12′. Surface water filtered; 50′x8′x8′.
1903 Metropolitan.	....	....	....	Surface water supply.
....	*1912* Tubular wells; 9–2½″x17′–27′.	....	....	Tubular wells; 9–2½″x17′–27′.

TYPES OF GROUND WATER SUPPLIES

MUNICIPALITY AND OWNER OF SOURCE OF SUPPLY.	Prior to 1870.	1871–1880.	1881–1890.	1891–1900.
LOWELL City.	....	*1872* Filter gallery; 1300′x8′x8′. Surface water filter also.	....	*1892* Tubular wells; 15 test wells. *1893* 44–6″x47′–67′. *1894* 5–6″ and 21–4″. 2 push wells. *1895* 120–2″x45′–50′, 169–2½″x27′–40′. *1900* 52–2½″.
LYNN City.	....	*1871* Reservoir (surface). *1880* Tubular wells.	*1884* Tubular wells abandoned. Additional surface supply.	....
MALDEN 1870 City. 1898 Metropolitan.	*1870* Pond supply.	....	*1889* Tubular wells; 51–2½″x35′–90′ Av. 65′.	*1892–1894* 48–Av. 60′. *1894* 26–2½″x Av. 41′. *1898* Metropolitan.
MANCHESTER Town.	....	....	....	*1892* Dug well; 32′ dia.x29′ with 5–2½″x24′ tubular wells in bottom. *1893* 6–4″x22′ in bottom. *1895* 5–4″x27′–54′.
MANSFIELD 1888 Mansfield Water Supply District. 1920 Town.	....	....	*1888* Dug well; 25′ dia.x20′.	....
MARBLEHEAD 1888 Marblehead Water Co., also supplied Swampscott and Nahant. 1889 Town supply.	....	....	*1885* (See Swampscott.) *1889* Tubular wells.	*1891* Dug well; 30′ dia.x34′. *1892* Tubular wells; 5–25′–53′. *1893* Dug well; 9′ dia.x8′. Tubular wells; 39–2½″ and 3″x25′–58′. Salt water trouble. *1895* Dug well to replace 9′ dia. well; 25′ dia.x33½′.
MARION Town.	....	....	....	....
MARSHFIELD W. V. Everson.	....	....	....	....
1890 Brant Rock Water Co.	....	....	*1888* Tubular well; 1¼″x27′. *1890* Dug well; 10′ dia.x17′.	....
1900 Humarock Beach Water Co.	....	....	....	*1900* Tubular wells; 4 or 5–2½″x22′.
1928 Town.	....	....	....	....
MATTAPOISETT Town.	....	....	....	....

AND DATES OF INSTALLATION—*Continued.*

1901–1910.	1911–1920.	1921–1930.	Since 1930.	In Use, 1935.
1901 125–2½″.	*1912* 128–2½″, several from year to year. *1916* Iron removal plant. *1919* Total of 550–2½″ wells.	Wells driven and re-driven.	*1935* Gravel packed wells in progress of installation; 35–6″ dia.x35′, 1–36″ dia.x35′.	Tubular wells; 620–2½″x25′–50′. Iron removal plant.
....	....	....	....	Surface water supply.
....	....	....	....	Surface water supply.
1901 Tubular wells; 20–3″x about 41′. *1909* Pond.	....	....	....	Dug well; 32′ dia.x29′, with tubular wells in bottom; 5–2½″x24′, 6–4″x22′. Tubular wells; 5–4″x27′–54′, 20–3″x about 41′. Also surface water supply.
....	....	....	....	Dug well; 25′ dia.x20′.
1909 Iron removal plant.	*1912* Dug well; 25′ dia.x31′. Collecting ditches. Tubular wells; 16–2½″x34′–73′.	....	....	Dug well; 25′ dia.x33½′. Tubular wells; 16–2½″x34′–73′. Iron removal plant.
1908 Tubular wells; 16–2½″x20′–30′. *1910* 8–2½″x20′–30′.	*1915* Tubular wells; 13–2½″x31′–39′, 5–2½″x28′.	*1929* Tubular wells; 3–2½″x31′–34′.	*1934* 11–2½″x25′–30′.	Tubular wells; 33–2½″x20′–30′, 18–2½″x31′–39′.
....	....	....	Dug well; 2′ dia.x8′.	....
....	*1911* Dug well; 27′ dia.x19′. *1920* Dug well; 18′ dia.x16′.	*1927* Dug well; 22′ dia.x19′.	....	Taken over by town.
....	*1920* Tubular wells; 2 or 3–2½″x22′.	....	....	Taken over by town.
....	....	*1927* Tubular wells; 48–2½″x20′–36′. *1930* 12–2½″x20′–36′.	....	Dug well; 22′ dia.x19′. Tubular wells; 7–2½″x22′, 60–2½″x20′–36′.
....	*1913* Tubular wells; 15–2½″x24′–28′.	*1923* Tubular wells; 9–2½″x24′–28′. *1924* 24–2½″x28′–35′.	....	Tubular wells; 24–2½″x24′–28′. 24–2½″x28′–35′.

Types of Ground Water Supplies

Municipality and Owner of Source of Supply.	Prior to 1870.	1871–1880.	1881–1890.	1891–1900.
Maynard Town.	....	....	*1889* Pipe line from pond laid with open joints to collect ground water also.	....
Medfield 1889 Medfield Water Co. 1921 Town. 1933 Medfield State Hospital.	....	Springs at private factory.	*1889* Dug well; 8′ dia.x6′.	....
Medford 1870 City. 1898 Metropolitan.	*1870* Pond.	....	....	*1893* Tubular wells; 14-2½″x30-52″. *1898* Metropolitan.
Medway Town.	....	....	....	....
Melrose 1870 City. 1898 Metropolitan.	*1870* Pond.	....	....	*1893* Tubular wells, private company; 15-2½″x35′-45′. *1898* Metropolitan.
Merrimac Town.	....	....	....	....
Methuen 1875 Supplied by Lawrence. 1894 Town.	....	*1875* Supplied by Lawrence.	....	*1894* Tubular wells; 27-2½″x25′-37′, 18-2½″x25′-32½′. *1897* 22-2½″x25′-55′. *1900* 33-2½″x25′-55′.
Middleborough 1885 Middleborough Fire District. 1919 Town.	....	....	*1885* Dug well; 26′ dia.x22′.	....
Milford and Hopedale 1855 Milford Aqueduct Co. 1881 Milford Water Co.	*1855* Springs.	....	*1881* Dug wells; 1-19′ dia.x26′, 1-14½′ dia.x25′, 1-22′ dia.x28′.	*1895* Open filters for river water.
Millbury Millbury Water Co.	....	....	....	*1895* Dug well; 20′ dia.x20′.
Millis 1891 Millis Water Co. 1894 Town.	....	....	....	*1891* Open excavations; 1-10′x25′x5′, 1-30′ dia.x5′. *1895* Dug well; 24′ dia.x10′. Rectangular well covered.
Milton 1890 Hyde Park Water Co. 1902 Town. 1903 Metropolitan.	....	....	*1890* Hyde Park Water Co. tubular wells.	....
Monson Town.	....	....	....	*1895* Dug well; 73′ dia.x23′.

AND DATES OF INSTALLATION—*Continued.*

1901–1910.	1911–1920.	1921–1930.	Since 1930.	In Use, 1935.
....	Pipe line relaid with tight joints.	....	....	Surface water supply.
1901 Dug well; 10′ dia.x9′.	....	....	*1933* Medfield State Hospital. Tubular wells; 64–2½″x29′–46′.	Medfield State Hospital supplies town by contract. Tubular wells; 64–2½″x29′–46′.
....	....	....	....	Surface water supply.
....	*1911* Tubular wells; 30–2½″x32′–75′. *1916* Dug wells; 5–24″x28′. *1917* 5–24″x28′. *1918* 4–24″x28′.	....	....	Tubular wells; 4–2½″x Av. 28′. Dug wells; 14–24″x28′.
....	....	....	....	Surface water supply.
1904 Tubular wells; 18–2½″x35′ Av.	*1916* Tubular wells; 10–2½″x23′–46′.	....	....	Tubular wells; 28–2½″x23′–46′.
1902 Tubular wells; 50–2½″x25′–55′. *1910* 4–8″x25′–55′.	*1911–1912* Dug wells; 1–3 ¾′ dia., 1–4′ dia., 1–7′ dia., 1–7′ 2″ dia. Av. 30′–40′.	*1921* Tubular wells: 34–2½″x20′x30′. *1930* Gravel packed wells; 3–16″ dia.x83′, 76′, 94′, 36″ dia.	*1932* Gravel packed well; 16″ dia.x83; 36″ dia. *1934* Gravel packed wells; 2–18″dia.x40′,42″ dia.	Gravel packed wells; 3–16″ dia.x83′, 36″ dia., 76′, 94′, 1–18″ dia.x40′ 42″ dia. Tubular wells; 34–2 ½″x20′–30′.
....	*1913* Iron removal plant.	....	....	Dug well; 26′ dia.x22′. Iron removal plant.
1902 Covered filter.	....	....	....	Dug wells; 1–14½′ dia.x25′, 1–22′ dia.x28′. Filtered surface water supply also.
Charging reservoirs.	....	....	....	Dug well; 20′ dia.x20′. Charging reservoirs.
....	....	*1922* Dug well; 20′ dia.x10′. *1930* Dug well; 25′ dia.x23′.	....	Dug wells; 1–10′x25′x5′, 1–24′ dia.x10′, 1–20′ dia.x10′, 1–25′ dia.x23′.
1903 Metropolitan.	....	....	....	Surface water supply.
1904 Surface water supply.	*1912* Additional surface water supply.	*1925* Dug well; 110′x15′x12′.	....	Dug wells; 1–73′ dia.x23′, 1–110′x15′x12′. Surface water supply also.

Types of Ground Water Supplies

Municipality and Owner of Source of Supply.	Prior to 1870.	1871–1880.	1881–1890.	1891–1900.
Montague (Village) E. L. Bartlett	....	....	....	....
Nahant See Swampscott. Marblehead Water Co.	....	....	*1885* Marblehead Water Co., dug well.	*1898* Metropolitan.
Nantucket Wannacomet Water Co.	....	*1878* Pond.	....	....
Siasconset Supply owned by Town.	....	....	....	....
Natick Town.	....	*1874* Pond.	....	*1897* Tubular test wells.
Needham Town.	....	....	*1890* Dug well; 22′ dia.x24′.	*1899* Tubular wells; 6–2½″x10′–30′. *1900* Dug well; 20′ dia.x30′.
Newburyport 1881 Newburyport Water Co. 1895 City.	....	....	*1881* Springs and collecting basin. Dug wells; 1–18′ dia.x13′, 1–27½′ dia.x11′, 1–23′ dia.x25′.	*1893* Dug well; 1–47′ dia.x16′. *1898* Spring and basin.
Newton 1876 Town. 1898 Metropolitan.	....	*1876* Filter basin, 1575′x70′x80′; tubular wells in bottom, 25′–35′. Tubular wells; 4–6″; 4–4″.	*1890* Filter gallery 2220′x4′x4′ of which 732′ replaced old filter basin. Tubular wells in bottom. 174–2½″x21′–130′.	*1892* Remainder of filter basin replaced by filter gallery. *1894* Filter gallery, double 24″ dia.x3268′, connected to tubular wells; 52–2½″x35′ Av. *1898* Metropolitan.
North Adams 1848 North Adams Water Co. 1875 North Adams Fire District. 1913 City.	*1848* Springs. *1861* Reservoirs (surface).	....	*1884* Drilled wells; 2–8″x550′–625′, terminating in a sandstone seam. *1890* Reservoirs (surface).	....
North Attleborough 1884 North Attleborough Fire District No. 1. 1892 Town.	....	....	*1884* Dug well; 25′ dia.x29′, smaller well in bottom; 10′ dia.x10′.	....
Northbridge Whitin Machine Works.	*1870* Filter gallery; 24′x15′x7′. Spring; 7′ dia.x4′.	....	*1889* Reservoir fed by springs and collecting drains.	*1891* Drilled well; 6″ dia.x550′. *1896* Spring.
Norton 1910 Norton Water Co. 1923 Town.	....	....	....	....
Norwood Town.	....	....	*1885* Pond.	*1900* Tubular wells, test wells; 6–2½″x27′–34′.

AND DATES OF INSTALLATION—*Continued.*

1901–1910.	1911–1920.	1921–1930.	Since 1930.	In Use, 1935.
....	*1911* Springs; 30″ dia.x4′.	....	....	Springs; 30″ dia.x4′.
....	....	....	....	Surface water supply.
....	*1911* Tubular wells; 40–2″x8′–10′. *1913* 23–2″x25′. Dug well; 2–8′ dia.x22′.	Dug wells; 2–8′x22′.	Tubular wells; 51–2″x28′.	Tubular wells; 121–2″–25′–28′. Dug wells; 4–8′ dia.x22′.
1904 Dug well; 8′ dia. 2 tubular wells in bottom. Tubular well.	*1912* Tubular wells.	*1924* Dug well; 10′ dia.x28′. *1927* Dug well; 15′ dia.	....	Dug wells; 3–8′, 10′ and 15′ dia.
1903 Dug well; 31′ dia.x25′.	....	....	....	Dug well; 31′ dia.x25′.
1903 Spring and collecting drains, 1566′. Charging reservoir, 7 acres.	*1914* Tubular wells; 5–2½″.	*1924* Tubular wells; 18–2½″x10½′–19½′.	*1931* 38–2½″x25′–30′. *1934* 12–2½″x30′–38′.	Dug wells; 1–22′ dia.x24′, 1–20′ dia.x30′. Charging reservoir, 7 acres. Spring and collecting drains, 1566′. Tubular wells; 50–2½″x Av. 35′.
1903 Drilled wells; 4–6″x100′–175′. *1904–1905* 16–6″x87′–190′. *1906* 6–6″x87′–252′. *1908* Filter surface supply added.	....	....	*1934* Filters for mixed ground and surface water.	Surface water supply. Also dug wells, old deep wells, springs and collecting basins. All filtered.
1909 Extension of filter gallery; 1420′x12″ dia. Charging bowls for river water.	*1911* Dug well; temporary, 10′ dia.x18′, enlarged to 28′ dia.x38′.	*1927* Dug well; 33′ dia.x41′. *1928–1934* Charging bowls for river water.	*1931* Treatment with soda ash.	Filter gallery; 4′x4′. Dug wells; 1–28′ dia.x38′, 1–33′ dia.x41′. Charging bowls. Surface water supply. Treatment with soda ash.
....	*1914* Reservoir (surface).	....	Deep wells not used since 1932.	Surface water supply.
1905 Dug well in Plainville; 28′ dia.x30′, gravity to pumping station.	....	....	....	Dug wells; 1–25′ dia.x29′, with 10′ dia. x 10′ in bottom, 1–28′ dia.x30′. Gravity flow.
1902–1910 Reservoirs (surface). Filters.	*1917–1918* Tubular wells; 10–2″ and 4″x18′–25′. Charging ditch.	*1922* Tubular wells; 26–2″x13′ Av.	....	Tubular wells; 10–2″ and 4″x18′–25′. Charging ditch, 26–2″x13′ Av.
....	*1912* Tubular wells; 20–2½″x30′–40′.	....	....	Tubular wells; 19–2½″x30′–40′
1905 Test wells; 9–2½″x25′–32′.	*1911* Test wells; 8–2½″x24′–30′. *1911–1920* Tubular wells; 75–2½″x24′–35′, 24–2½″x24′–35′. Charging ditch. Dug well: 12′ dia.x30′.	*1921* Tubular wells; 43–2½″x24′–45′.	....	Tubular wells; 131–2½″x24′–45′. Surface water supply also.

Types of Ground Water Supplies

Municipality and Owner of Source of Supply.	Prior to 1870.	1871–1880.	1881–1890.	1891–1900.
Oak Bluffs Cottage City Water Co.	....	....	*1890* Springs. Collecting drains; 1–12″ dia.x525′, 2–6″ dia.x130′. Charging reservoir; 0.3 acres.	....
Orange 1873 New Home Sewing Machine Co. 1874–1914 Fall Hill Water Co. 1893 Town.	....	*1873* Spring stored in open reservoir.	....	*1893* Surface water supply. *1895* Spring; 130′x75′x10′.
Oxford Oxford Water Co.	....	....	....	....
Palmer 1886 Palmer Water Co. 1921 Palmer Fire District No. 1.	....	....	*1886* Reservoirs (surface).	....
1908 Boston Duck Co. 1932 Bondsville Water Co.	....	....	....	....
George B. Cheney	....	....	....	....
Palmer Mills-Otis Co.	....	....	....	....
C. Healy	....	....	....	....
J. J. Kelly	....	....	....	....
Paxton Town.	....	....	....	....
Peabody Danvers & Salem Aqueduct Co. Town.	*1799* Springs; later from pond.	....	....	....
Pepperell Town.	....	....	....	....
Plainville 1909 Town. 1919 North Attleborough.	....	....	....	....
Plymouth 1833 Plymouth Aqueduct Co. 1855 Town.	*1833* Springs. *1855* Ponds.	....	....	....
Provincetown Town.	....	....	....	*1893* Tubular wells; 6–5″x28′ Av., abandoned in 1898. *1898* Open basin.
Quincy 1884 City. 1897 Metropolitan.	....	....	*1884* Dug wells; 1–30′ dia.x22′, 1–32′ dia.x27′. *1888* Reservoir (surface).	*1897* Metropolitan.
Reading Town.	....	....	....	*1891* Filter gallery; 250′x3½′x4′ in a meadow subject to flowage. *1896* Mechanical filter; iron removal.

AND DATES OF INSTALLATION—*Continued.*

1901–1910.	1911–1920.	1921–1930.	Since 1930.	In Use, 1935.
1909 Charging reservoir; 0.1 acre. Collecting drains; 6″ and 8″.	....	....	....	Springs. Collecting drains; 2151′x4″–12″ dia. Charging reservoirs; 0.4 acres.
....	....	....	....	Spring; 130′x75′x10′. Surface water supply also.
1906 Tubular wells; 8–2½″x19′–30′.	*1914* Tubular wells; 7–2½″x26′–30′.	*1925* Tubular wells; 10–2½″x26′–30′.	....	Tubular wells; 25–2½″x19′–30′.
....	....	*1922* Tubular wells; 8–2½″x30′ Av.	....	Tubular wells; 8–2½″x30′ Av. Surface water supply also.
1908 Tubular wells; 6–6″x18′–48′.	4–6″x22′–52′.	....	....	Tubular wells; 10–6″x18′–52′.
....	....	....	....	Large collecting well and 30 springs. Tubular wells; 3–2½″x28′.
....	....	....	....	20 springs. Tubular well; 6″–250′.
....	....	....	....	3 springs; 1–40′x15′ in plan x7′, 1–20′x10′ in plan x14′, 1–34′x10′ in plan x8′.
...	...	...	...	Spring; 48″ dia.x7′.
....	....	....	*1934* Spring; 168′x39′x5′.	Spring; 168′x39′x5′.
....	....	....	....	Surface water supply.
1909 Tubular wells; 34–2½″x19′–27′.	....	....	....	Tubular wells; 34–2½″x19′–27′.
1909 Tubular wells; 7–2½″.	*1919* Supplied from No. Attleborough. Tubular wells abandoned.	....	....	Dug wells (see North Attleborough).
....	....	....	....	Surface water supply.
1905 Deep well, abandoned; 420′. *1906* Iron removal tests. Supply abandoned in 1908. *1907* Tubular wells; 20–2½″x30′ Av.	*1913* Salt water trouble. *1914* 4–2½″x30′ Av. *1918* 9–2½″x30′ Av.	*1923* Salt water trouble. *1924* 8–2½″. *1928* 26–2½″.	*1932* Salt water trouble. Several wells redriven with new strainers and to a uniform depth.	Tubular wells; 50–2½″x21′–41′.
....	....	....	....	Surface water supply.
....	*1915–1917* Drilled wells; 1–8″x267′, 4–8″x500′. Surface water supply.	....	*1930–1934* Tubular wells; 80–2½″x38′ Av.	Tubular wells; 76–2½″x38′ Av. Iron removal plant recommended.

TYPES OF GROUND WATER SUPPLIES

MUNICIPALITY AND OWNER OF SOURCE OF SUPPLY.	Prior to 1870.	1871–1880.	1881–1890.	1891–1900.
REVERE 1884 Revere Water Co. 1905 City. 1898 Metropolitan.	....	....	*1884* Dug well; 30′ dia.x20′, 3–6″ and 2–2″, tubular wells in bottom. Dug well; 40′ dia.x20′, smaller well; 8′ dia.x30′ and 8–2″ wells in bottom. Tubular wells, 3 groups.	*1892* Intrusion of salt water. *1891* Tubular wells in Saugus; 5–2″x75′, 9–2½″x34′–97′. *1892* 11-2½″x26′–47.4′. *1893* 9–2½″x30′–100′. *1894* 20–2½″x30′–100′. *1895* 15–2½″x30′–100′. *1896* Saline taste in Revere wells. *1898* Revere wells abandoned and Metropolitan supply taken in part.
ROCKPORT Town.	....	....	....	*1895* Pond.
RUSSELL Town.	....	....	....	....
SALEM 1799 Salem & Danvers Aqueduct Co. 1866 City. 1913 Salem & Beverly Water Supply Board.	*1799* Springs; later from ponds. *1866* City supply surface water.	....	....	....
SALISBURY Artesian Water Co. 1915 Salisbury Water Supply Co.	....	....	....	....
SCITUATE 1893 Scituate Water Co. 1932 Town.	....	....	....	....
SHARON 1885 Sharon Water Co. 1895 Town.	....	....	*1885* Dug well; 16′ dia.x16′.	....
SHEFFIELD Sheffield Water Co.	....	....	....	*1897* Springs and reservoir; 1–16′x32′x7′, 1–60′x80′x10′ (partly surface water).
SHELBURNE and BUCKLAND Shelburne Falls Fire District.	....	....	*1885* Springs.	....
SHIRLEY Shirley Villag Water District.	....	....	....	....

AND DATES OF INSTALLATION—*Continued.*

1901–1910.	1911–1920.	1921–1930.	Since 1930.	In Use, 1935.
....	....	....	....	Surface water supply.
....	....	*1924* Tubular wells; 4–2½"x22'–28'. *1930* 4–2½".	....	Tubular wells; 8–2½"x22'–28'. Surface water supply also.
....	*1911* Reservoir (surface).	....	*1931* Tubular wells; 2–2½"x43'–54'. *1934* Gravel packed well; 18" dia.x26', 42" dia.	Tubular wells; 2–2½"x43'–54'. Gravel packed well; 18" dia.x26', 42" dia. Surface water supply.
....	....	....	....	Surface water supply.
Drilled wells; 2–110'. Tubular wells; 10–15'–40'.	*1914* Dug well; 35' dia.x23'. *1915* Dug well; 40' dia.x22'. Charging reservoir. *1920* Dug well; 41' dia.x16'.	....	....	Dug wells; 1–40' dia.x22', 1–41' dia.x16'. Charging reservoir.
1901 Tubular we 30–2½"x35'–45'. *1904* 5–2½"x35'–45'. *1910* Dug well; 20' dia.x22'.	*1913* Dug well; 25' dia. x 25', later used as a pump well. Filtered surface water supply.	*1926* Tubular wells; 2–2½"x44'–66', 1–6"x44'–66'. *1927* Tubular wells; 16–6"x35'–66'.	*1930* Gravel packed wells; 1–18" dia.x60', 1–18" dia.x70½'. Deep tubular well; 8" dia.x115'. *1933* Gravel packed well; 18" dia.x21', 45" dia. *1934* 1–4"x42'.	Dug well; 20' dia.x22'. Tubular wells; 30–2½"x35'–45'. Gravel packed wells; 1–18" dia.x60', 1–18" dia.x72½', 1–8" dia.x118', 1–18" dia.x21', 1–16" dia.x42'.
1901 Tubular wells; 4–2½"x21'–30'. *1906* 9–2½"x19'–50'.	*1911* Tubular wells; 4–2½"x21'–30'.	*1923* Tubular wells; 9–2½"x27'–51'. *1926* 12–2½"x19'–50'. *1930* 10–2½"x19'–50'.	....	Dug well; 16' dia.x16'. Tubular wells; 8–2½"x21'–30', 40–2½"x19'–51'.
....	....	....	*1934* Storage basin; 20'x40'x7'. 2 new springs.	Spring; 16'x32'x7'. 2 springs to storage basin; 20'x40'x7'.
....	*1912* Reservoirs (surface).	....	....	Surface water supply.
1903 Filter gallery; 50'x8'x10'.	Dug wells; 4–18' dia.x18'.	....	....	Filter gallery; 50'x8'x10'. Dug wells; 4–18' dia.x18'.

TYPES OF GROUND WATER SUPPLIES

MUNICIPALITY AND OWNER OF SOURCE OF SUPPLY.	Prior to 1870.	1871–1880.	1881–1890.	1891–1900.
SHREWSBURY Town.	....	....	....	....
SOMERSET Town.	....	....	....	....
SOUTHAMPTON 1900 Mt. Spring Water Co. 1931 Town.	....	....	....	*1900* Springs; 1–30″ dia.x4′, 1–3½′x3½′x3′, 1–6′ dia.x10′, 1–4′x5′x4′.
SOUTH HADLEY South Hadley Fire District No. 2.	....	....	....	....
SPRINGFIELD 1848 Springfield Aqueduct Co.	*1798, 1848 and 1850* Springs. *1860* Dug well; 10′ dia.x20′. Collecting drain; 1950′x7″ pipe.	....	....	....
STOCKBRIDGE Stockbridge Water Co.	*1851* Springs. *1862* Reservoir (surface).	....	*1884* Drilled wells; 1–8″x300′, 1–8″x600′.	*1892* Surface water supply.
The Hill Water Co.	*1885* Springs; 1–20′x26′x3′, 2–4′x5′x3½′. Storage reservoir 16′x40′x7′.	....	....	....
STOUGHTON 1886 Stoughton Water Co. 1892 Town.	....	....	*1886* Dug well; 25′ dia.x30′, partly in ledge.	*1893* Dug well; 6′ dia.x39′. Old well abandoned. Cut off wall in valley to hold back ground water. Charging reservoir abandoned. Collecting drains to well. Surface supply.
STURBRIDGE Various Associations. 1933 Town.	....	*1876* Spring and well. (Sturbridge Aqueduct Co.)	....	....
SUNDERLAND Sunderland Water Co.	....	....	*1884* Springs; 2–4′ dia.x4′.	....
SUTTON Sutton Water Co.	....	....	....	....
SWAMPSCOTT 1888 Marblehead Water Co. 1898 Town. Metropolitan.	....	....	*1888* Dug well; 26′ dia.x20′, tubular wells in bottom; 6–2″x50′–75′. *1890* Tubular wells; 72–2½″x40′.	*1892* Tubular wells; 26–2½″x43′–57′, gravity flow. *1895* Tubular wells; 10–2½″x30′–47′, affected by salt water. *1898* Metropolitan.

and Dates of Installation—*Continued.*

1901–1910.	1911–1920.	1921–1930.	Since 1930.	In Use, 1935.
....	*1915* Tubular wells; 19–2½"x21'–29'.	*1923* Tubular wells. *1924* 31–2½"x20'–27'. *1925* 16–2½"x18'–29½', 22–2½"x about 25'.	*1933* Gravel packed well; 36" dia.x30', 78" dia. *1934* 1–36" dia.x30', 78" dia., 3–36" dia.x30' and 24', 78" dia.	Gravel packed wells; 2–36" dia.x30', 78" dia., 3–36" dia.x24' and 30', 78" dia. 15 tubular wells; 2½"x about 25'.
....	....	*1927* Tubular wells; 45–2½"x28'–35'.	*1933* Soda ash treatment.	Tubular wells; 45–2½"x28'–35'.
....	....	....	*1931* Supplied by Holyoke.	Surface water supply.
....	*1911* Dug well; 25 dia.x12'. Collecting drains; 300'x8" pipe. *1915* Charging reservoir. *1918* Dug well; 30' dia.x12'.	....	*1932* Surface water filtered.	Dug wells; 1–25' dia.x12', 1–30' dia.x12'. Collecting drain; 300' of 8" pipe. Filtered surface water supply.
....	....	....	....	Surface water supply.
....	....	....	....	Surface water supply.
....	....	....	....	Springs; 1–20'x26'x3', 2–4'x5'x3½'. Storage reservoir; 16'x40'x7'.
....	....	....	....	Surface water supply.
....	....	Dug well; 9' dia.x13'.	*1933* Tubular wells; 15–2½"x25'–36'.	Tubular wells; 15–2½"x25'–36'.
....	....	*1929* Reservoir (surface).	....	Surface water supply.
....	*1914* Dug well; 10' dia.x22'. *1918* Drilled well; 2½" dia.x285'.	....	....	Dug well; 10' dia.x22'. Drilled well; 2½" dia.x285'.
....	....	....	....	Surface water supply.

Types of Ground Water Supplies

Municipality and Owner of Source of Supply.	Prior to 1870.	1871–1880.	1881–1890.	1891–1900.
Taunton City.	....	*1876* Filter gallery; 863′x5′x4′, tubular wells in bottom; 1-1¼″x25′, 1-1½″x37′. Filter bank 94.6′ of gallery with 40′ of filter of crushed stone and gravel between it and the river. Filter basin; 400′x17′x18′.	*1889* Drilled well; 8″x975′, 70,000 g.p.d. never used.	*1894* Surface water supply.
Tisbury 1887 Vineyard Haven Water Co. 1905 Town.	....	....	*1887* Spring. Collecting gallery; 38′x7′x10′.	....
Townsend Town.	....	....	....	....
Uxbridge 1879 Uxbridge Water Co. Town.	....	*1879* Springs on side hill, 650′ of collecting drains.	....	*1896* Dug well; 30′ dia.x8′, auxiliary.
Wakefield Wakefield Water Co. Town.	....	....	*1883* Lake (surface).	....
Walpole Town.	....	....	....	*1896* Tubular wells; 6-2½″x28′-70′, 34-2″x28′-70′.
Waltham City.	....	*1873* Filter basin ¼ acre x8.4′ deep.	....	*1891* Dug well; 40′ dia.x26.4′ in filter basin; both covered in 1893.
Ware Town.	....	....	*1886* Dug well; 26′ dia.x23′.	*1893* Spring; 9′ dia.x6′. Tubular wells; 12-2½″x28′-39′, gravity flow.
Wareham Wareham Fire District.	....	....	....	....
Warren Warren Aqueduct Co.	....	Dug wells; 2 long and narrow x14′, 1-2½″dia.x20′	....	....
Warren Water District.	....	....	....	....
1912 Thorndike Co. 1932 West Warren Water Co.	....	....	....	....

AND DATES OF INSTALLATION—*Continued.*

1901–1910.	1911–1920.	1921–1930.	Since 1930.	In Use, 1935.
....	....	....	....	Surface water supply. Filter gallery for emergency only.
....	....	....	*1935* Additional collecting drain.	Spring with collecting drains; 38′x7′x10′.
....	....	....	*1934* Tubular wells; 35–2½″x30′–70′, Av. 40′.	Tubular wells; 35–2½″x30′–70′, Av. 40′.
1906 Tubular wells; 16–2½″x26′–35′.	....	*1924* Tubular wells; 17–2½″x28′–38′.	....	Tubular wells; 33–2½″x26′–38′.
....	....	*1930* Tubular wells; 16–2½″x20′–50′.	*1931* Tubular wells; 11–2½″x20′–30′.	Surface water supply. Tubular wells; 27–2½″x20′–50′.
....	*1918* Tubular wells; 61–2½″x34′–61′.	....	....	Tubular wells; 67–2½″x28′–70′, 34–2″x28′–70′.
1908 Dug well; 30′ dia.x35′.	....	....	....	Dug well and covered filter basin; ¼ acre x8′, 40′ dia.x26.4′. Dug well; 30′ dia.x35′. Iron removal plant contemplated.
1905 Tubular wells; 8–2½″. *1908* 1–2½″. *1909* 3–2½″x34′ Av. *1910* 6–2½″x35′ Av.	*1911* 6–2½″x37′ Av. *1914* 4–2½″x36′ Av.	....	....	Tubular wells; 40–2½″x27′–40′. Dug well; 26′ dia.x23′. Spring; 9′ dia.x6′.
1908 Tubular wells; 22–2½″x31′–43′.	....	*1925* 10–2½″x30′–43′. *1928* 21–2½″x28′–35′.	*1933* 11 wells disconnected due to high CO_2. *1935* 11 test wells.	Tubular wells; 32–2½″x28′–43′.
....	....	....	....	....
....	....	*1922* Tubular wells; 20–2½″x30′–50′.	....	Tubular wells; 20–2½″x30′–50′.
....	*1912–1915* Dug well; 20′ dia.x18′. *1920* Dug well; 60′x12′x18′.	....	....	Dug wells; 1–20′ dia.x18′, 1–60′x12′x18′.

TYPES OF GROUND WATER SUPPLIES

MUNICIPALITY AND OWNER OF SOURCE OF SUPPLY.	Prior to 1870.	1871–1880.	1881–1890.	1891–1900.
WATERTOWN 1885 Watertown Water Supply Co. 1897 Town. 1898 Metropolitan.	....	....	*1885* Filter galleries; 190′x15′x12′–15′, 175′x3′x2′, 102′x8′.	*1891* Tubular wells; 25–2½″x25′ Av. Dug well; 20′ dia.x24′. Filter gallery of perforated pipe. *1893* Deep tubular wells; 2–8″x250′. Tubular wells; 16–2½″x30′ Av. 3–6″x30′ Av. *1898* Metropolitan.
WAYLAND Town.	....	*1878* Filter gallery; 560′x1′x1½′. Reservoir (surface).	....	....
WEBSTER 1881 H. L. Slater. 1894 Town.	....	....	*1881* Lake (surface).	*1893* Dug well; 25′ dia.x30′.
WELLESLEY Town.	....	....	*1884* Filter gallery; 63′x12′x18′. *1886* Dug well; 22′ dia.x20′.	*1897* Tubular wells; 33–2½″x30′–60′. Gravity flow at first.
WESTBOROUGH Town.	....	*1879* Filter basin and charging reservoir.	....	....
WEST BROOKFIELD West Brookfield Aqueduct Co.	*1838* Side hill gallery; 160′x2½′x8′.	....	....	....
Quaboag Aqueduct Co.	*1852* Dug wells.	....	....	....
Cement Aqueduct Co.	....	*1872* Side hill gallery; 160′x3′x6′	....	....
Town.	....	....	....	....
WESTFORD Westford Water Co.	....	....	....	....
Brookside Water Co.	....	....	....	....
WESTMINSTER Westminster Aqueduct Co.	....	....	*1890* Springs; 1–60′x20′x8′, 1–40′x12′x9′.	....
WESTON 1896 Weston Aqueduct Co.	....	....	....	*1896* Dug well; 10′ dia.x22′.
1921 Town.				*1900* Tubular wells; 11–2½″x22′–25′.
Weston Water Co.	....	....	....	....
Glen Farm Water Co.	....	....	....	....

AND DATES OF INSTALLATION—*Continued*.

1901–1910.	1911–1920.	1921–1930.	Since 1930.	In Use, 1935.
....	....	....	....	Surface water supply.
....	....	*1925* Tubular wells; 30–2½"x35'–60'.	*1933* Gravel packed well; 6" dia.x48'.	Tubular wells; 30–2½"x35'–60'. Gravel packed well; 6" dia.x48', 12" dia. Surface water supply for part of town.
1901 Filter gallery and crib. 30'x10'x shallow prepared filter bank. 36'x15'. *1903* Tubular wells; 26–2½"x35'–65'. *1909* 14–6".	....	*1924* 20–2½". *1926* 30–2½".	....	Dug well; 25' dia.x30'. Tubular wells; 76–2½"x35'–65'. 14–6"x35'–65'.
....	*1915* Tubular wells; 17–2½"x30'–65'.	*1924* Tubular well; 10" dia.x30¾'. *1927* Dug well; 25' dia.x40'.	....	Filter gallery; 63'x12'x18'. Dug wells; 1–22' dia.x20', 1–25' dia.x40'. Tubular wells; 1–10" dia.x30¾', 50–2½"x30'–65'.
....	....	....	....	Filter basin below reservoir formed by diking off part of pond.
....	....	....	....	....
....	....	....	....	....
....	....	....	....	....
....	*1913* Tubular wells; 10–2½"x22'–35'.	....	....	Tubular wells; 10–2½"x22'–35'.
1908 Tubular wells; 10–2½"x35' Av.	*1917* Tubular wells; 9–2½"x40'–60'. Dug well; 2½' dia.x34'.	....	....	Tubular wells; 19–2½"x35'–60'. Dug well; 1–2½' dia.x34'
....	*1920* Tubular wells; 7–2½"x38'–41'.	....	....	Tubular wells; 7–2½"x38'–41'.
....	....	....	....	Springs; 1–60'x20'x8', 1–40'x12'x9'.
1910 12–2½"x25'–28'.	....	*1929* 18–2½".	....	Dug well; 10' dia.x22'. Tubular wells; 11–2½"x22'–25', 30–2½"x25'–28'.
....	....	....	....	Dug wells; 1–12' dia.x25', 1–20'x20'x30'.
....	....	....	....	Dug wells; 2–20' dia.x15'.

TYPES OF GROUND WATER SUPPLIES

MUNICIPALITY AND OWNER OF SOURCE OF SUPPLY.	Prior to 1870.	1871–1880.	1881–1890.	1891–1900.
WEST SPRINGFIELD (Mittineague)	....	....	....	*1893* Dug well; 25′ dia.x14′. *1895* Spring.
WEST STOCKBRIDGE East Mountain Water Co.	....	*1873* Springs.	....	....
WESTWOOD Westwood Water Co.	....	....	....	....
Dedham Water Co.	....	....	....	....
WHITMAN 1883 Town. 1905 Supplied from Brockton.	....	....	*1883* Filter galleries; 100′x15′x14′, 416′x18′x20′.	*1891* Drilled well; 6″ dia.x227′ Pond connection.
WILLIAMSTOWN Williams Aqueduct Co.	*1796* Springs. *1859* Springs.	*1880* Springs.	*1888* Springs; 250′x250′x12′, 200′x200′x16′.	....
1847 Williamstown Water. 1885 Company.	*1848* Springs: 1–50′x30′x5′, 1–90′x38′x7.7′.	....	....	Reservoirs.
WILMINGTON Town.	....	....	....	....
WINCHENDON Town.	....	....	....	*1896* Dug well; 28½′ dia.x25′. Collecting drain; 1065′x6″–12″ pipe with open joints.
WINTHROP 1884 Revere Water Co. 1898 Metropolitan.	....	....	*1884* Revere Water Company.	*1898* Metropolitan.
WOBURN Town.	....	*1873* Filter gallery; 82′x12′x9′.	....	....
WORCESTER 1798 Daniel Goulding	*1798* Spring.	....	....	....
WORTHINGTON Worthing Fire District.	....	....	....	....
WRENTHAM Straw Factory. 1907 Town.	....	....	....	....
YARMOUTH Town.	....	....	....	....

AND DATES OF INSTALLATION—*Concluded.*

1901–1910.	1911–1920.	1921–1930.	Since 1930.	In Use, 1935.
....	....	....	....	Surface water supply.
....	....	*1922* Reservoir for springs, 10′x10′x6′.	....	Springs and surface water supply.
1901 Tubular wells.	....	....	....	Tubular wells; 6–2″x15′–25′, 2–2½″x15′–25′.
....	....	....	....	Also Dedham Water Co. Tubular and dug wells.
1905 Supplied from Brockton.	....	....	....	Surface water supply supplied from Brockton.
....	....	....	....	....
....	....	....	....	Surface water supply. Springs; 1–50′x30′x5′, 1–90′x38′x7.7′.
....	....	*1925* Tubular wells; 16–2½″x45′–64′. *1927–1928* 26–2½″x45′–85′.	....	Tubular wells; 42–2½″x45′–85′.
1910 Dug well; 40′ dia.x35′.	....	*1923* Charging reservoir constructed.	....	Dug wells; 1–28½′ dia.x25′, 1–40′ dia.x35′. Charging reservoir.
....	....	....	....	Surface water supply.
1907 Dug well; 20′ dia.x30′. *1908* Tubular wells; 50–2½″x38′–40′.	....	*1927* Gravel packed well; 26″ dia.x40′, 38″ dia.	*1932* Gravel packed wells; 1–18″ dia.x70′,30″dia., 1–18″ dia.x56′,30″dia., 1–18″ dia.x62½′, 30″ dia.	Gravel packed wells; 1–26″ dia.x40′, 38″ dia., 1–18″ dia.x70′,30″ dia., 1–18″ dia.x56′, 30″ dia., 1–18″ dia.x62½′,30″dia.
....	....	....	....	Surface water supply.
....	*1911* Springs and collecting reservoir, 0.15 acre.	....	....	Springs and collecting reservoir.
1908 Tubular wells; 10–2½″x20′–35′. *1910* 12–2½″.	....	*1929* Dug wells; 30″ dia.x20′–26′.	*1931* Dug wells; 3–30″ dia.x20′–26′. *1933* 3–30″ dia. *1934* 1–30″ dia.	Tubular wells; 21–2½″x20′–35′. Dug wells; 7–30″.
....	....	....	*1931* Tubular wells; 14–2½″x30′–47′. *1933* 6–2½″x30′–47′.	Tubular wells; 20–2½″x30′–47′.

state. In anticipation of this question a map (Fig. 1) has been prepared which includes also the ground water supplies that have been abandoned in favor of surface water supplies. When the Metropolitan Water District was formed, local municipal supplies were soon abandoned with the exception of the Brookline and Newton supplies. The city of Lawrence, like the neighboring city of Lowell, in the early years of its municipal supply took water from the ground near the Merrimack River. While Lowell developed additional ground water sources to meet its growing demands, Lawrence turned to a more abundant supply of river water, not appreciating the danger of the use of polluted water until later. The town of Stoughton experienced difficulty with its ground water supply and at the present time is furnished with surface water. The city of Taunton is supplied with surface water except that on occasions when it is necessary to clean the reservoirs temporary use is made of the old ground water works. The old supply of Provincetown, located in the town, was abandoned several years ago because of the large amount of iron present in the water and a new supply was developed in the town of Truro. In North Adams, elimination of several leaks discovered in a study of water consumption and a drop in industrial activity made it unnecessary for several years to use the deep tubular wells. These have virtually been abandoned. The ground water supplies in use in former years in Amherst, Cheshire, Chicopee, Shelburne, Southampton and West Springfield became inadequate with increased water consumption, and these ground water sources were abandoned for more abundant surface water supplies. With these exceptions, municipalities which have adopted ground water supplies have continued to use them, although some are now employed only as auxiliary sources or have been replaced by works in different locations.

For those who may not be familiar with the various methods of taking water from the ground, sketches have been prepared with the dual purpose of explanation and the avoidance of lengthy text. These sketches are reproduced in Figs. 4–16.

The data shown in the accompanying table have been rearranged with careful selection of the various types of works installed during each decade since 1870. Diagrammatic tabulation of this information shows through the decreasing or increasing number of installations, the favor in which each type has been held and also the transition from one type to another as progress in the art of developing ground water supplies took place. Figures 2 and 3 present this summary for consideration and also serve as a ready reference to show the municipalities in which different types of works have been used.

Methods of Obtaining Water from the Ground. Wells have been in common use as a means of tapping subterranean waters for centuries. It is only natural, therefore, with the experience of the old world to guide them, that the early settlers in this country should have depended upon wells for private water supply wherever it was not possible to find a natural spring

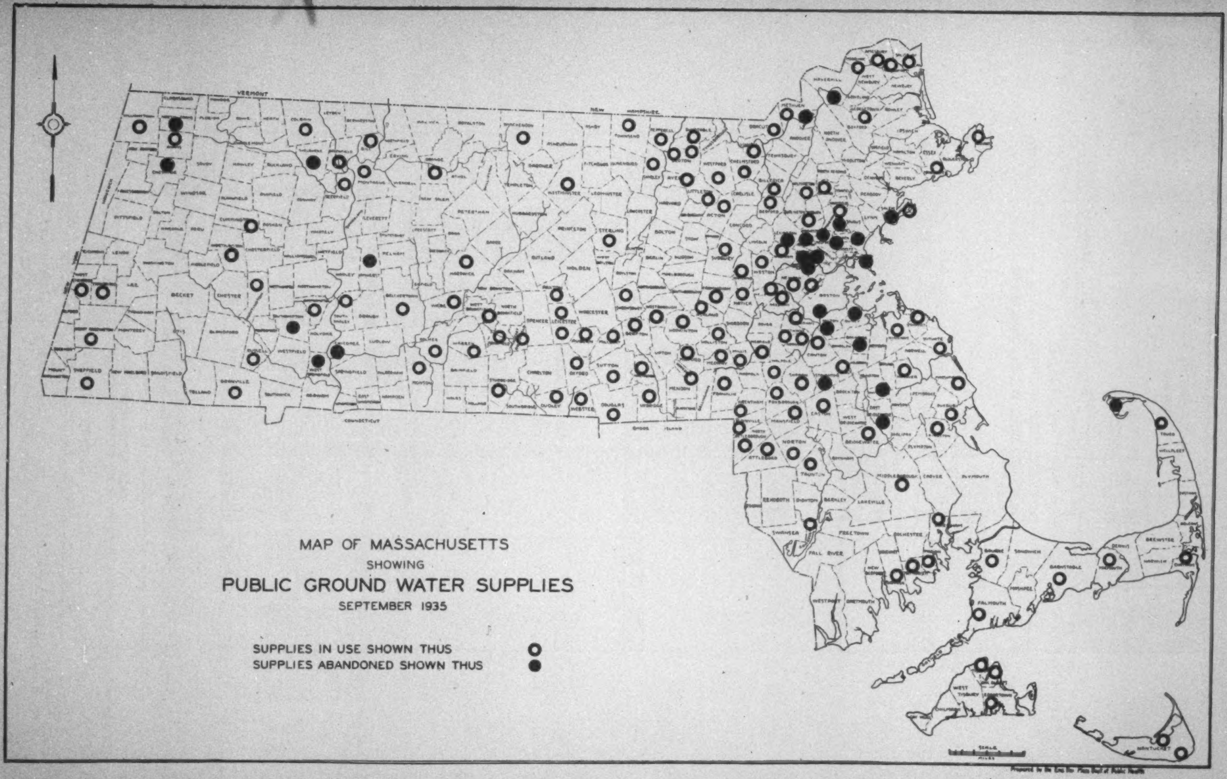
MAP OF MASSACHUSETTS
SHOWING
PUBLIC GROUND WATER SUPPLIES
SEPTEMBER 1935
SUPPLIES IN USE SHOWN THUS ○
SUPPLIES ABANDONED SHOWN THUS ●
VERMONT
NEW HAMPSHIRE
CONNECTICUT
RHODE ISLAND
BOSTON
FALL RIVER
NANTUCKET
SCALE
MILES
Prepared by the Eng. Div. Mass. Dept. of Public Health

FIG. 1.

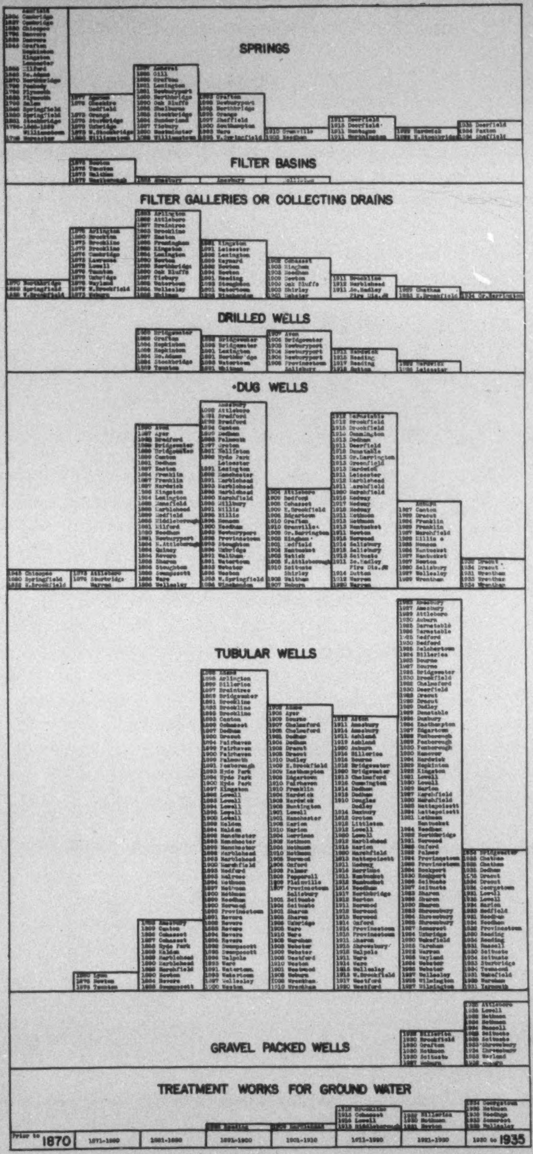
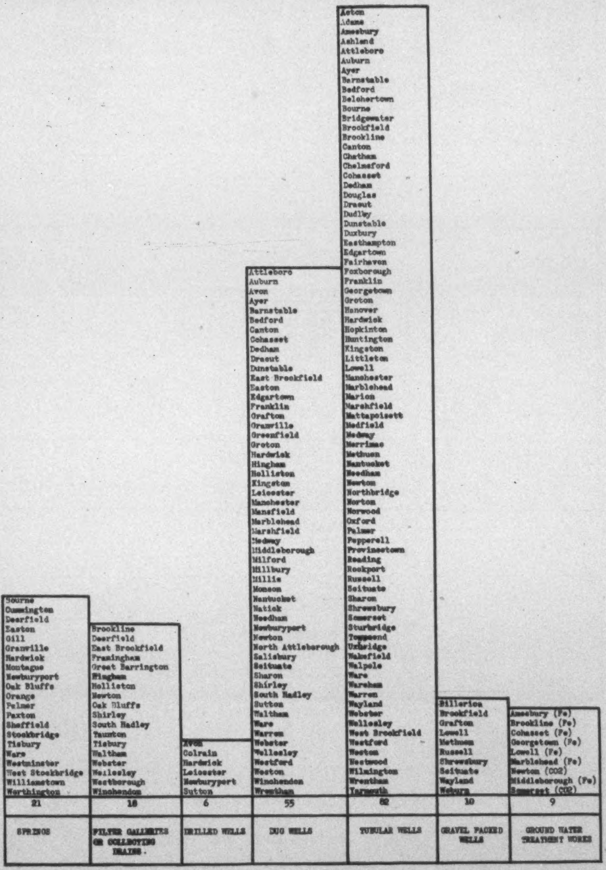


Fig. 2.—Changes in Installation of Different Types of Massachusetts Ground Water Supplies.



Bourne
Cummington
Deerfield
Easton
Gill
Granville
Hardwick
Montague
Newburyport
Oak Bluffs
Orange
Palmer
Paxton
Sheffield
Stockbridge
Tisbury
Ware
Westminster
West Stockbridge
Williamstown
Worthington

21

SPRINGS

Brookline
Deerfield
East Brookfield
Framingham
Great Barrington
Hingham
Holliston
Newton
Oak Bluffs
Shirley
South Hadley
Taunton
Tisbury
Waltham
Webster
Wellesley
Westborough
Winchendon

18

FILTER GALLERIES OR COLLECTING DRAINS.

Avon
Colrain
Hardwick
Leicester
Newburyport
Sutton

6

DRILLED WELLS

Attleboro
Auburn
Avon
Ayer
Barnstable
Bedford
Canton
Cohasset
Dedham
Dracut
Dunstable
East Brookfield
Easton
Edgartown
Franklin
Grafton
Granville
Greenfield
Groton
Hardwick
Hingham
Holliston
Kingston
Leicester
Manchester
Mansfield
Marblehead
Marshfield
Medway
Middleborough
Milford
Millbury
Millis
Monson
Nantucket
Natick
Needham
Newburyport
Newton
North Attleborough
Salisbury
Scituate
Sharon
Shirley
South Hadley
Sutton
Waltham
Ware
Warren
Webster
Wellesley
Westford
Weston
Winchendon
Wrentham

55

DUG WELLS

Acton
Adams
Amesbury
Ashland
Attleboro
Auburn
Ayer
Barnstable
Bedford
Belchertown
Bourne
Bridgewater
Brookfield
Brookline
Canton
Chatham
Chelmsford
Cohasset
Dedham
Douglas
Dracut
Dudley
Dunstable
Duxbury
Easthampton
Edgartown
Fairhaven
Foxborough
Franklin
Georgetown
Groton
Hanover
Hardwick
Hopkinton
Huntington
Kingston
Littleton
Lowell
Manchester
Marblehead
Marion
Marshfield
Mattapoisett
Medfield
Medway
Merrimac
Methuen
Nantucket
Needham
Newton
Northbridge
Norton
Norwood
Oxford
Palmer
Pepperell
Provincetown
Reading
Rockport
Russell
Scituate
Sharon
Shrewsbury
Somerset
Sturbridge
Townsend
Uxbridge
Wakefield
Walpole
Ware
Wareham
Warren
Wayland
Webster
Wellesley
West Brookfield
Westford
Weston
Westwood
Wilmington
Wrentham
Yarmouth

82

TUBULAR WELLS

Billerica
Brookfield
Grafton
Lowell
Methuen
Russell
Shrewsbury
Scituate
Wayland
Woburn

10

GRAVEL PACKED WELLS

Amesbury (Fe)
Brookline (Fe)
Cohasset (Fe)
Georgetown (Fe)
Lowell (Fe)
Marblehead (Fe)
Newton (CO2)
Middleborough (Fe)
Somerset (CO2)

9

GROUND WATER TREATMENT WORKS

FIG. 3.— TYPES OF MASSACHUSETTS GROUND WATER SUPPLIES IN USE IN 1935.

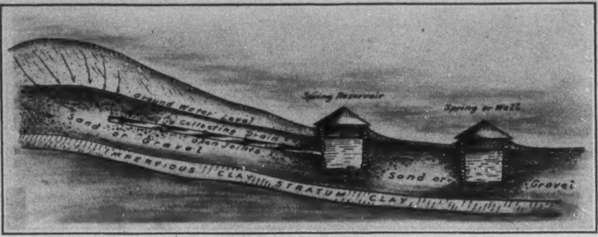

Spring Reservoir
Spring or Well
Ground Water Level
Collecting Drain
Open Joints
Sand or Gravel
IMPERVIOUS CLAY STRATUM CLAY
Sand or Gravel

Fig. 4.— Springs.

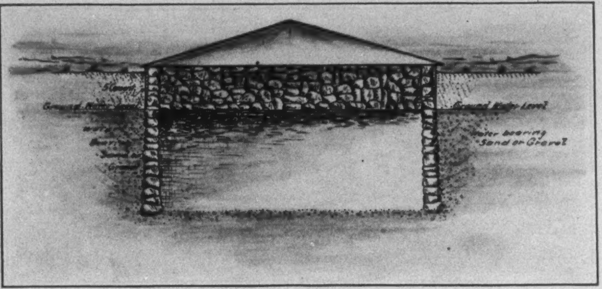

Ground Water Level
Ground Water Level
Water bearing Sand or Gravel
Water bearing Sand or Gravel

Fig. 5.— Large Dug Well.

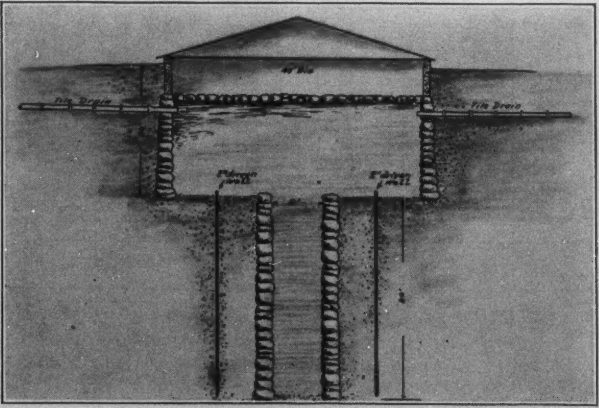

Tile Drain
Tile Drain
2" driven well
2" driven well

Fig. 6.— Modified Dug Well.
Small diameter deep well and tubular wells sunk in bottom of original shallow well.

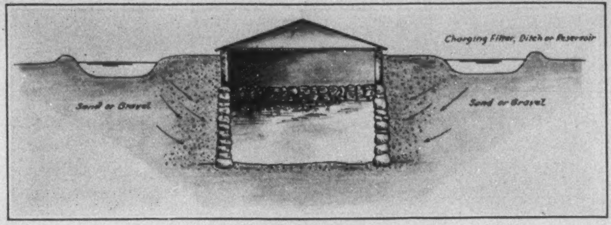

Charging Filter, Ditch or Reservoir
Sand or Gravel
Sand or Gravel

FIG. 7.— MODIFIED DUG WELL.
Charging filter, ditch or reservoir provided to increase yield.

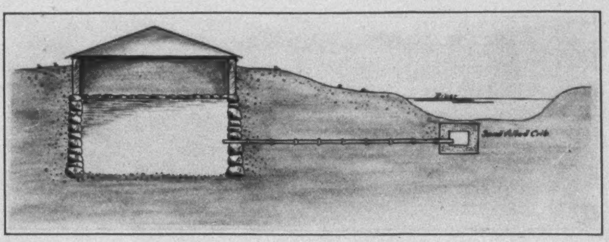

River
Sand-filled Crib

FIG. 8.— WELL AND FILTER CRIB.
Crib constructed around intake pipe in stream.

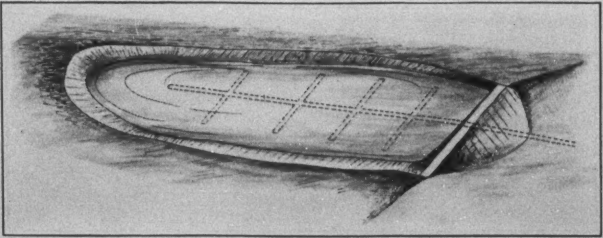


FIG. 9.— UNDERDRAINED RESERVOIR.

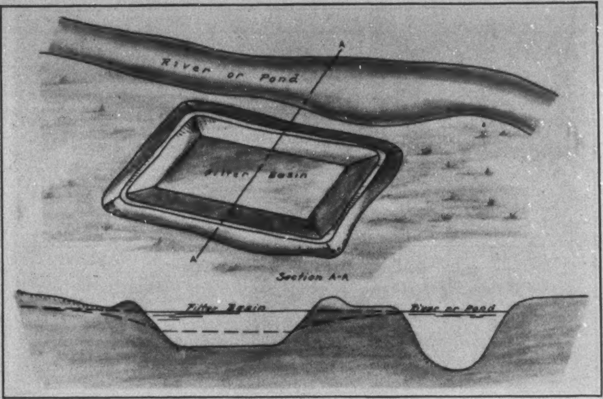

River or Pond
A
Filter Basin
A
Section A-A
Filter Basin
River or Pond

FIG. 10.— FILTER BASIN.

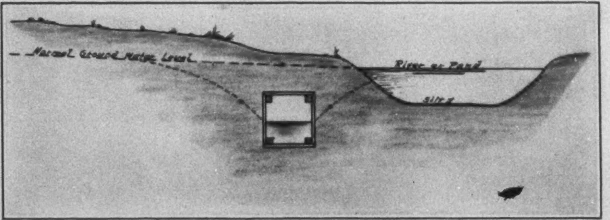

Normal Ground Water Level
River or Pond
Silts

FIG. 11.— FILTER GALLERY.

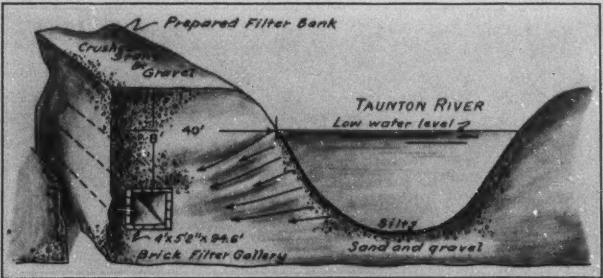

Prepared Filter Bank
Crushed Stone or Gravel
TAUNTON RIVER
Low water level
40'
8'
4'x5'2"x94.6'
Brick Filter Gallery
Silts
Sand and gravel

FIG. 12.— FILTER BANK.

(Fig. 4). The absence of economical means of pumping led to the search for springs at higher elevations than the dwellings to be served in order that water might be piped to them by gravity. The first public ground water supplies were developed after this manner, and even today there exists a local prejudice in favor of gravity supplies based no doubt upon the general opinion of former years that there existed a balance of economy over the use of a pumped supply. Walton H. Sears* as a part of his paper on "Pumping Water," gave a review of the history of pumping water in this country. It is interesting to conclude from his statements, taken in conjunction with Figs. 2 and 3, that when means of economical pumping became available, ground water supplies came into greater use.

With private wells as an example, the first public wells were made similar but larger with the expectation that they would yield the greater quantity needed for a public supply (Fig. 5). Unfortunately this did not always have the desired result, and available records show that direct connections to a nearby pond or stream were maintained for emergency use, such as drought or fire.

Attempts to increase the yield of dug wells took the form of sinking smaller but deeper wells in the bottom or by driving or drilling tubular wells in the bottom (Fig. 6). This procedure failed in its attempt to bring more water to the site, and collecting drains came into use which in some instances were laid radially from the well. Ditches or filters supplied with surface water were constructed near the well in an effort to charge the ground with water (Fig. 7). Direct connections to streams or ponds were officially frowned upon, and attempts to meet the situation sometimes took the form of installing filter cribs around the end of the intake pipes (Fig. 8). Artificial ground water was also developed by installing systems of underdrains and flooding the area with surface water (Fig. 9).

The fact that the most abundant store of ground water is to be found in the low lands led to the construction of elongated wells called filter basins parallel to rivers (Fig. 10). The first of these and certain dug wells, in the beginning merely open excavations, were later walled up or replaced by galleries or pipes laid in trenches and covered with a sufficient depth of soil to prevent the direct entrance of surface water (Fig. 11). This step was further hastened by complaints which arose against the disagreeable tastes and odors imparted to the waters of open basins or wells by the microscopic organisms which were found to grow abundantly in water drawn from the ground and stored in the presence of light. These latter types of works have come to be known as filter galleries. In one case an attempt to increase the yield of such galleries was made by excavating the natural material between the gallery and the river and replacing it with selected gravel. So far as the record shows, this was the only one of its kind and was known as a "filter bank" (Fig. 12).

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*This Journal Vol. 49, 1935, p. 119.)

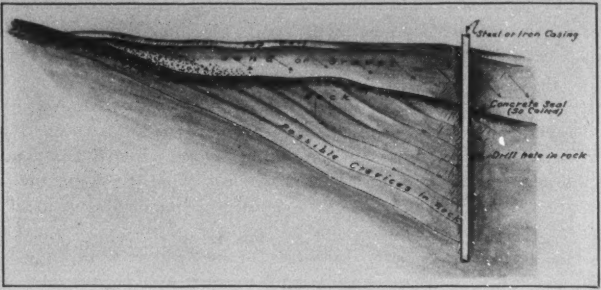
Sand or Gravel
Rock
Possible Crevices in Rock
Steel or Iron Casing
Concrete Seal (So Called)
Drill hole in rock

FIG. 13.— DRILLED WELL.

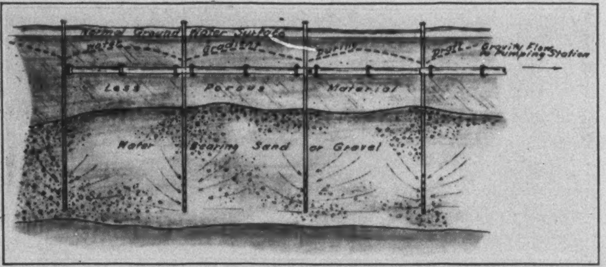
Normal Ground Water Surface
water gradient during draft
Gravity Flow to Pumping Station
Less Porous Material
Water Bearing Sand or Gravel

FIG. 14.— TUBULAR WELLS — GRAVITY FLOW.

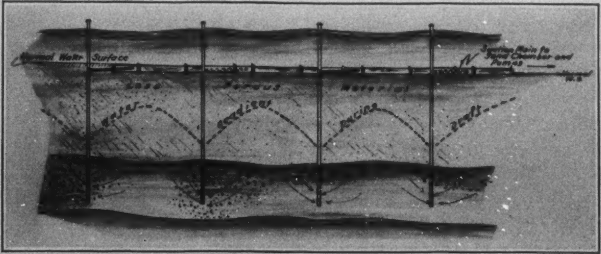
Normal Water Surface
Suction Main to Sand Chamber and Pumps
Normal W.S
Less Porous Material
water gradient during draft

FIG. 15.— TUBULAR WELLS — SUCTION LIFT.

The drilled well had a short life in the eastern part of Massachusetts principally because of the unproductiveness of the granite and other igneous rocks underlying the glacial deposits and because of the danger of pollution (Fig. 13). In the western part of the state certain deep drilled wells, said to have penetrated sandstone, furnished a somewhat better yield but were discarded because of the questionable quality of the water drawn from the populated area in which the wells were located. The deepest well of this kind, located in eastern Massachusetts, was drilled to a total depth of 975 ft. and produced a yield of 70 000 g.p.d. The optimism attendant upon the drilling of this well included the expectation of supplying not only the city in which it was located but also a neighboring city.

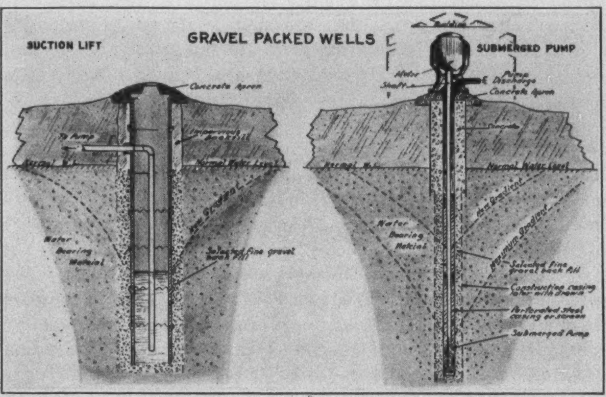
GRAVEL PACKED WELLS
SUCTION LIFT
SUBMERGED PUMP
Concrete Apron
To Pump
Normal W.L.
Normal Water Level
Water Bearing Material
Selected fine gravel back fill
Motor
Shaft
Pump Discharge
Concrete Apron
Concrete
Normal W.L.
Normal Water Level
Water Bearing Material
Maximum Gradient
Selected fine gravel back fill
Constructing casing later withdrawn
Perforated steel casing or screen
Submerged Pump

Fig. 16.— Gravel-packed Wells.

A paper presented before this Association in March, 1887, by Noyes, dates the beginning of the use of tubular wells in this country to about 1850, and Noyes wrote that the first private tubular well was driven experimentally in Somerville by Calvin Horton. This well was 1½ in. in diameter and 36 ft. deep. The first uses of tubular wells in connection with public supplies were in the bottom of dug wells or filter galleries, or in groups connected to discharge into such works by gravity. The tubular wells at Brookline were designed to discharge to the pump well by gravity, but as the art of making the connecting piping air tight progressed the collecting main was connected directly to the pumps and the wells then operated under suction. Tubular wells are installed with open ends in coarse gravel or with strainers where the sand is finer (Figs. 14 and 15).

The tendency of small tubular wells to become clogged has led to the development of a new type of well, known as the gravel packed well (Fig. 16).

This type of well is constructed by sinking a large casing to the depth desired for the finished well, and a smaller pipe is then inserted inside the outer casing. The annular space between the two casings is filled with selected gravel of a sufficient size readily to permit the flow of ground water to the inner pipe and small enough to act as a strainer to hold back the finer material in the surrounding soil. The portion of the inner casing below normal ground water level is perforated with holes or slots to admit the water without allowing the gravel packing to enter. The outer construction casing is withdrawn, leaving a well with its strainer surrounded with an outer secondary strainer of gravel. The success of this type of well lies in the fundamental fact that the velocity of approach of the water entering at the larger circumference at the outer limits of the gravel packing is low enough so that the water does not carry the fine material from the soil. Theoretically, finer water-bearing material should require a larger diameter of gravel packing.

Gravel packed wells may be classified in two groups: those which are connected with surface pumps by draw pipes and for convenience called gravel packed wells with suction lift, and those provided with pumps submerged in the inner casing below the maximum point to which it is desired to draw down the level of the ground water. Wells of each kind have been installed in connection with municipal works in Massachusetts. The advantages of this type of well may, however, be lost if due consideration is not given to the selection of a proper site for their installation and a considerable degree of engineering skill and judgment exercised in the interpretation of the results of the necessary preliminary explorations made to determine the character of the water-bearing material.

This type of well seeks to combine the low cost of construction of the tubular well with the advantages of the greater circumference and consequent lower velocity of approach of the water entering a dug well. From the standpoint of economy there appears to be a limit to the size of gravel packed wells and consequently a limit to the quantity of water which should be expected from each well. A feeling of conservatism leads to the conclusion that a greater measure of success will attend the adoption of this type of well if it is considered as a progressive member of the well family and not as an infant prodigy capable of startling performance. A step in the direction of the gravel packed well was taken when small dug wells lined with 24- to 48-in. tile pipe were in certain instances substituted for tubular wells where the fine soil clogged tubular wells.

Wells Near the Sea. Wells near the sea have in several instances given trouble by producing brackish water during times of drought or when increased draft upon them had lowered the natural fresh water level. This experience was encountered at Revere before the wells were abandoned in favor of the Metropolitan supply and more recently at the North Truro supply of the town of Provincetown. Studies in connection with the latter supply and a search of the literature on the subject show that this phenomenon was first studied and an explanation presented by Badon Gyhben, a Dutch engineer, in 1887. It was concluded that the sea water would penetrate under the land and stand at an elevation approximately equal to mean sea level if it was not for the fresh water which has passed downward through the soil to rest upon the salt water and to tend to displace it. The level of the ground water established by this fresh water load is governed by the conditions of rainfall, the amount which seeps into the soil and the gradient necessary to permit this water to flow through the ground to the ocean. At this point it may be instructive to introduce a diagram to assist in pursuing the matter further (Fig. 17).

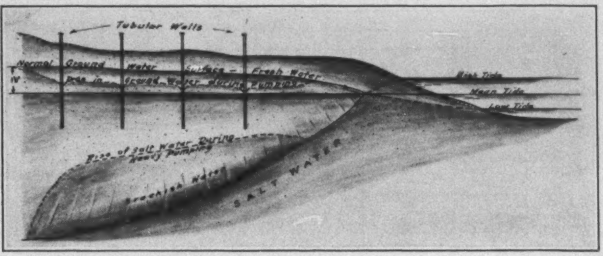
Tubular Wells
Normal Ground Water Surface – Fresh Water
Drop in Ground Water during Pumping
IV
High Tide
Mean Tide
Low Tide
Rise of Salt Water During Heavy Pumping
Brackish Water
SALT WATER

Fig. 17.— Wells near Salt Water.

The fresh water does not immediately mix with the salt water but tends to displace it, and because of the resistance of the soil to free movement of the salt water away from the field this displacement takes place in a vertical direction. When the load of fresh water has established its level at one foot above the normal salt water level the salt water will be found depressed about 38 ft., and a surcharge of fresh water to two feet above mean sea level or thereabouts will have depressed the salt water twice this amount. Greater loads of fresh water will bring about proportionally greater depressions of the salt water. Salt water is heavier than fresh water and from their known specific gravities it is computed that 39 ft. of fresh water will balance about 38 ft. of salt water. The fresh water underground near the sea is in balance with the salt water at the shore.

Tests for a supply of fresh ground water near the sea may be entirely successful, but continued pumping from wells may reduce the fresh water load so that the salt water will rise to the level of the bottom of the wells and the supply become salty. This does not usually take place suddenly but is evidenced by a gradual increase in the salinity of the water supply. At Provincetown, experiments showed that wells deeper than 15 ft. below the water level pumped brackish water and that it was only necessary to drive five feet deeper to obtain water which was one-tenth salt water. It was further found that clogged wells in one portion of the area resulted in a greater draft from other wells and caused the salt water to rise to them.

Figure 18 has been prepared to show the increased salinity of water drawn from tubular wells near salt water with increased water consumption, the age of the works and also improvements when additional wells were installed to spread the load over a greater area.

Obtaining a suitable supply of fresh water near the sea is essentially a skimming problem, and if the cream is thin or an attempt is made to skim too closely or too deeply in one spot the product will not be to one's liking.

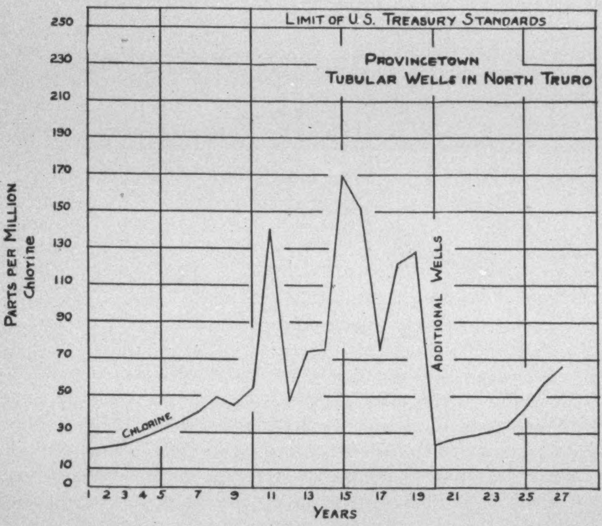

FIG. 18.— INCREASE IN SALINITY OF PROVINCETOWN TUBULAR WELLS.

Quality of Ground Water. Methods of obtaining water from the ground have been discussed at some length and a brief reference to the quality of ground waters should logically follow. In Massachusetts, the ground waters are relatively soft, and the hardest of them taken from limestone regions in the western part of the state rarely justify the adoption of water softening. Assuming that the site has been selected with good sanitary engineering judgment with due regard to avoiding sources of pollution, then the greatest concern of the water works official and his engineer is to obtain a water free from color, low in iron and manganese, and free from dissolved gases which may require removal to render the water fit for use. Of course the water should be of normal salinity. In most towns where suitable sand and gravel deposits exist, water may be obtained free from iron if the search is thorough. There have been, however, one or two instances where it was necessary to accept a water containing a considerable quantity of iron and to include iron removal plants in the initial developments.

While the majority of ground water supplies continue to produce water of acceptable quality, others have for one reason or another experienced a

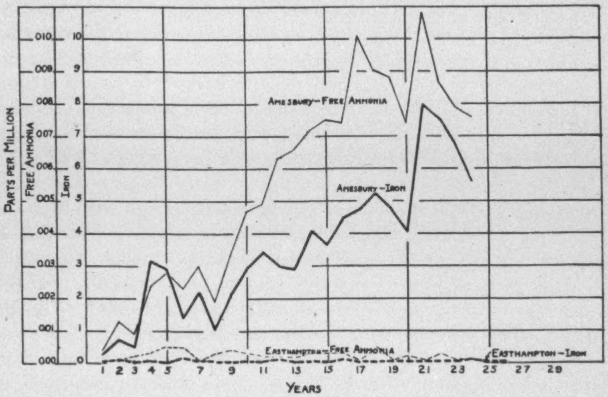

FIG. 19.— CHANGES IN WATER QUALITY OF TUBULAR WELLS. Measured in Terms of Iron and Free Ammonia.

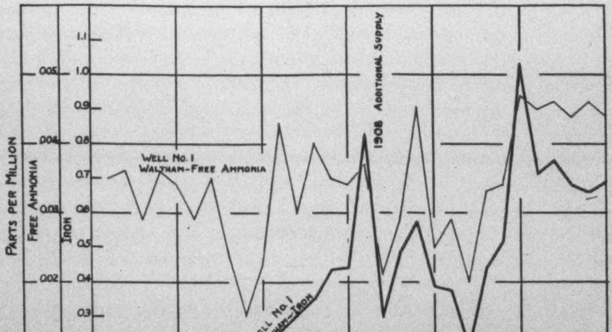

FIG. 20.— CHANGES IN WATER QUALITY OF DUG WELLS. Measured in Terms of Iron and Free Ammonia.

gradual deterioration in quality. Overpumping of a group of wells has resulted in drawing fine sand from the surrounding soil, and increased draft or drought has caused water to flow to the collecting works from underground areas remote from those originally tapped with a resultant change in the quality of the water pumped. Some of these remote areas contain water high in organic matter which results in the dissolving of iron from the soil through which the water passes on its way to the wells and in the formation of carbon dioxide which is an agent in rendering the water corrosive. Figures 19 and 20 show the changes which have taken place in the quality of the water of two supplies collecting water by means of tubular wells, and of two supplies using dug wells. These are selected because of their marked contrast to show the change in the iron content and the relatively higher amount of free ammonia in water having higher iron.

Usually a change in the color of a ground water supply is just cause for alarm because of the likelihood of a leak in the collecting system which may be admitting imperfectly filtered surface water. It is possible to draw colored swamp water from considerable distances through coarse gravel without the removal of color. By this same premise, however, it might be expected that bacteria associated with pollution might follow. Therefore, a colored ground water should be viewed with suspicion.

Changes in the chloride and nitrate content of the water may indicate a change of environment with the encroachment of population upon areas which, with more foresight, might have been reserved for the protection of the supply. This sort of change as well as the difficulty of finding new unpolluted areas from which to draw additional supplies was partly responsible for the formation of the Metropolitan Water District. An increase in the nitrate or carbon dioxide content of the water may take place concurrently with an increase in the iron content, but the carbon dioxide or nitrate content may increase independently of the iron.

Instances of improvement in the quality of a ground water after preliminary tests are rare, but in two cases it has been experienced. In one case the quantity of iron decreased materially during a pumping test to a much lower figure than that found in the water from exploration wells, and in another case the quantity of carbon dioxide decreased when the ground water had been lowered below its line of contact with an area of peat overlying the well field and after dilution with water entering the field from other areas.

While numerous records are available concerning variations in the amount of iron in water, the records of variations in the carbon dioxide content under changed conditions of draft are not plentiful.

Ground Water Treatment and Protection. Works for the treatment of ground water have been associated in Massachusetts principally with increased iron content. Such works have been of more or less uniform design providing aëration, percolation through coke or crushed stone, sedimentation, and filtration through sand at slow rates, the processes following in the order given. This type of treatment has been successfully used at six plants. At one plant preliminary treatment only by aëration, coke contact and sedimentation was adopted with the intention of adding slow sand-filters at a later date. Aëration and sedimentation alone is being practiced at still another plant until change in the quality of the raw water makes further treatment necessary.

Of late more attention has been paid to the corrosive quality of certain ground waters, and devices have been installed for the dosing of the water with chemicals where no further treatment has been required. The treatment of ground waters for the removal of iron or the correction of acidity give challenge to the engineer and chemist since it is by no means certain that the most economical design has yet been developed.

In order to conserve the advantages inherent in a ground water supply, it is important that due care be used in the selection of the site for the collecting works with a view to protection of the water from pollution on the watershed and to the possibilities for extending the works to obtain additional quantities of water. Sufficient testing at the site should be made to justify the installation of the final plant with the expectation that the quality of the water will be equal to that obtained from the test plant. The works should be enlarged from time to time to keep pace with the increased demands upon them in order to avoid damage by overdraft. Due regard should be given to the chemical characteristics of the water and corrective treatment instituted in time to avoid damage to the distribution system and house piping. Neglect of this precaution may give rise to complaints and result in a large economic loss due to corroded or clogged piping or interference with industrial processes which might have been avoided to the financial advantage of the community and the individual. In towns where there are lead service pipes, especial vigilance should be maintained, since the corrosion of lead pipe has been known to cause serious lead poisoning among those drinking the water.

Ground water supplies have found great favor in many municipalities because of their relative freedom from pollution, but regular tests should be made to insure that the works continue to be safe. Ill considered changes should be avoided. In one instance the bank of a stream adjacent to a dug well was excavated to permit the water of the stream to approach nearer to the well with the expectation that the yield of the well would be increased. The expectation was fulfilled, but the change also endangered the safety of the supply by permitting the surface water of the brook to flood around the well with the danger of the entrance of imperfectly filtered water. In certain instances, suction mains connecting tubular wells have settled causing the joints in the main to open and admitting air during times of low ground water stages or admitting swamp water during times of flood. Settlement of suction mains has also caused the tearing away of the goosenecks and other parts of the lateral connections to individual wells with similar results. Sometimes the settlement of a suction main has deranged the vertical alignment enough to form an air trap in the line, reducing the carrying capacity and increasing the vacuum required on the pumps. In view of these possible defects which may occur in the collecting system, it is becoming increasingly apparent that the flooding of well fields with surface water subject to pollution should be prevented. It has been suggested that the diking off of well fields which are subject to overflow from adjoining streams should be made standard practice. The engineer and water works official should also be alert during construction of collecting works to make certain that polluted soil is not used in filling around the wells or in their construction. This has happened in at least two instances, and several months elapsed before all trace of bacteria characteristic of sewage pollution had disappeared, even when attempts were made to chlorinate the material used for fill. There have been instances where large wells have been converted into collecting wells to receive the water from additional works and where a loss of water has occurred by escape into the ground surrounding the collecting well when the discharge into it was maintaining a water level above that in the surrounding ground.

It is suggested that every water works superintendent take account of stock at least once a year and test his ground water collecting system for leaks which may endanger the safety of his supply. He may also consider the method of sewage disposal at the pumping station and should assure himself that it cannot cause pollution of his supply and may interest himself in the character of the water which might flood the well field from neighboring streams. Tubular well systems may be tested for leaks by the use of compressed air, and similar tests may be made on suction pipes leading to dug wells or other works or on suction mains which pass under open streams. Ground water is normally low in color, and one of the simplest tests which can be made is the daily collection of a sample of water in the pumping station for comparison with that collected on previous days. By arranging these samples in front of a white cardboard, any change in color may be noted, and a search for the cause should begin immediately. The superintendent should also consider the capacity of his supply and the growing demands upon it, so that he may take steps to increase his plant before damage to the works or avoidable impairment of the quality of the water results from over pumping. He should at regular intervals consider the changes in the character of the water produced to determine what treatment, if any, should be applied to render the water more acceptable to the consumer and thus to maintain the good will essential to the conduct of all utilities whether publicly or privately owned.

Conclusion. In closing this paper let us question whether or not there has been a measure of overconfidence concerning ground water supplies. Ground water is naturally filtered surface water, and the same care and consideration should be taken to avoid pollution in drawing it from the ground as in the protection of water which has been artificially filtered.

Acknowledgment is hereby made of the patience and skill of Miss Margaret M. Enwright in preparing the intricate tabulations for publication.

THE WATER SUPPLY OF A STATE INSTITUTION.

BY BAYARD F. SNOW.*

[*Read September 19, 1935.*]

The State Prison Colony of the Massachusetts Department of Correction is located at Norfolk, Mass., about 25 miles south of Boston, in the valley of the Stop River, a tributary of the Charles. Here, on land originally acquired by the state for other purposes, is being constructed an institution or group of institutions which will eventually house a large part of the prison population of the state.

By 1930, when the author first became connected with the project, some progress had been made in the institution and a potential source of water supply had been located by the State Department of Public Health. Exploratory and test wells had been driven at various points in the valley southerly or upstream from the proposed location, and ten wells had been connected and tested by continuous pumping for a week in September of the previous year. The results of these tests indicated that the water was of excellent quality and probably ample in quantity for the proposed institution, at least for ordinary domestic and industrial use. The wells used during the pumping test were believed to be sufficient to supply the Colony until material increase in population made additional collecting works necessary. This has proven true, and until June 1935 the entire supply for the rapidly growing institution has been taken from these ten tubular wells. During the past year, however, they have been taxed to their full capacity to meet the needs of the construction program, which increased the draft to such an extent as to require almost continuous pumping.

A public institution bears many points of resemblance to a town of similar size: A group of people bound together by geographical ties, living and working side by side, frequently have nothing more in common than the physical association forced by economic, physical or statute laws. Such a group, however, whether civic or institutional, creates a demand for water for its personal and industrial needs, a demand which varies with the population, its personal habits and the nature of its industries.

Many of our towns have found it expedient to take their water from the ground. So, too, most of our state institutions find the ground-water supply most readily available and easiest to protect from pollution. To discover the best available source of supply and to develop that supply in the best manner always has complications which tend to make each case an individual problem. There are certain generalities which apply to the distinction between supplies for towns and those for institutions. For example, it can be assumed that an institution has a more orderly growth, a planned program of development which makes the problem more nearly resemble those found in the text books than is usually the case. We find, too, that the institutional habits are more regular and that the variations in demand are consequently greater than in the case of a municipality of similar size. The use of water by a large group of people, all rising, washing, eating, working and having their recreation according to a regulated program makes for marked peaks of demand as well as for similarity of daily patterns in the demand curve. In an institution, therefore, we see a tendency toward a more definitely planned growth of population and industry, together with regular daily peak demands which are much more pronounced in their departure from the average consumption than is the case with municipal supplies. From the former it would appear that the engineer has only to learn the plan of development, and he can know for how many he has to provide. The study of population statistics, business trends, school enrollments, telephone installations, comparison with other similar populations and all devices frequently resorted to in the attempt to predict future population and water use are not only unnecessary but useless.

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*Consulting Engineer, Boston, Mass.

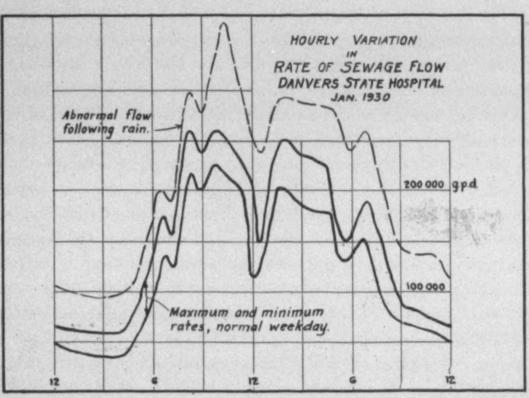
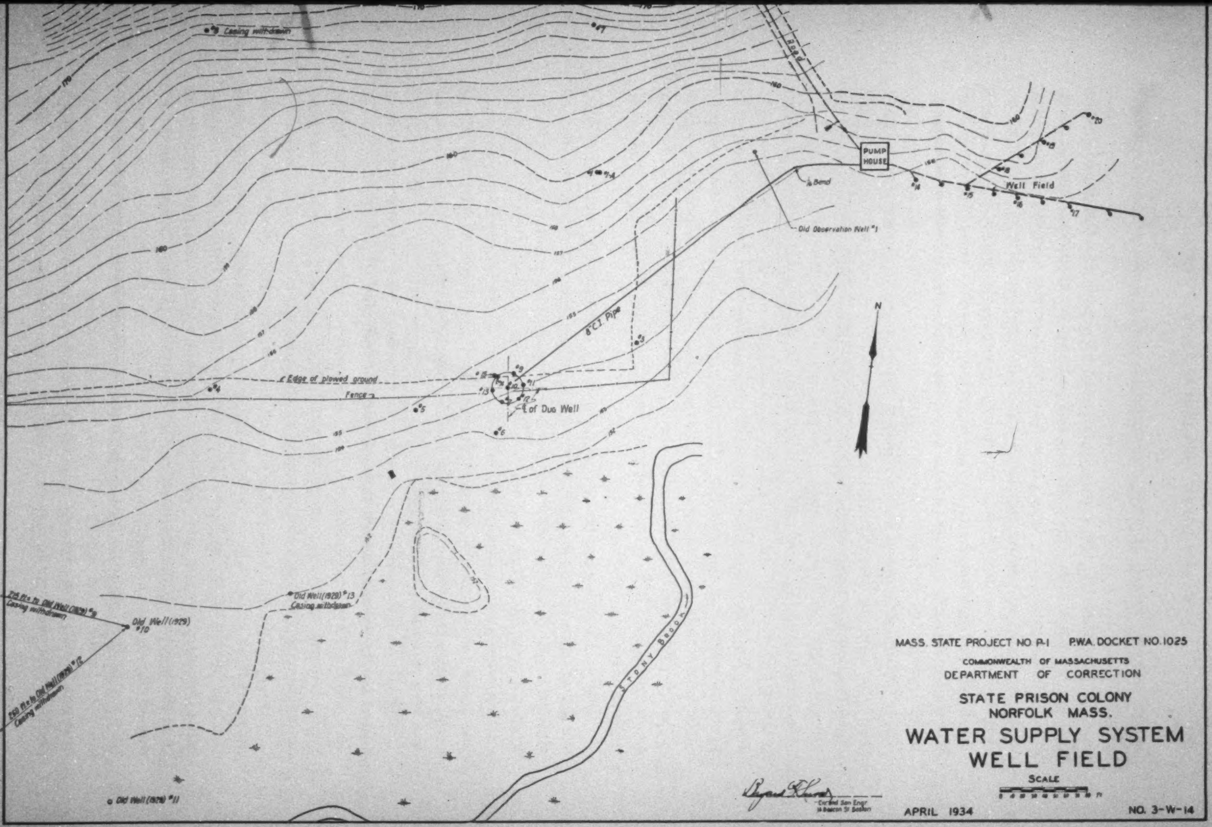


FIG. 1.

To learn the plan of growth which will be followed, however, is not as easy as it may seem. Public policy changes, comparatively trivial incidents draw public attention to the institutions, and pressure is brought to bear on officials and executives to scatter the institutions over a greater area, making them smaller, or on the other hand, to concentrate more and more institutions on lands already acquired for such use. We find therefore that the plan of growth is more apt to be changed on short notice than is the case with municipalities and that in most cases the changed plan is



Casing withdrawn
Road
PUMP HOUSE
Well Field
¼ Bend
Old Observation Well #1
8" C.I. Pipe
Edge of plowed ground
Fence
℄ of Duo Well
160
170
155
STONY BROOK
Old Well (1929) #13
Casing withdrawn
275 Ft's to Old Well (1929) #9
Casing withdrawn
Old Well (1929) #10
250 Ft's to Old Well (1929) #12
Casing withdrawn
Old Well (1929) #11
N
MASS. STATE PROJECT NO P-1 P.W.A. DOCKET NO. 1025
COMMONWEALTH OF MASSACHUSETTS
DEPARTMENT OF CORRECTION
STATE PRISON COLONY
NORFOLK MASS.
WATER SUPPLY SYSTEM
WELL FIELD
SCALE
Ft
Civ and San Engr
14 Beacon St Boston
APRIL 1934
NO. 3-W-14

FIG. 2.

made without much if any consideration for the water supply needs. (Figure 1.)

In planning for the normal and peak demands for the State Prison Colony we took into consideration not only personal and industrial needs but also the possibility that fire or riot might create a heavy draft. Two elevated tanks are provided, each of 150 000 gal. capacity, one being located near the main from the pumping station to the walled enclosure and the other beyond the distribution loop which supplies the buildings within the wall so as to permit its use in case of temporary shut down of the supply main and thus to provide two sources for water. In studying a fire supply, consideration was given to emergency fire pumps, so located as to draw from the river or from an underground reservoir to be provided and filled from the regular supply. It was evident, however, that extension of the ground-water collecting system would soon be necessary to meet the increasing demand, and when under P.W.A. some such additional works seemed likely to be authorized, the opportunity was given to increase the system. No large deposit of coarse water-bearing sand had been found in previous tests, but the tributary drainage area could be expected to supply more water than the reasonably anticipated demand. The problem was to collect it and supply the ordinary needs of the Colony and at the same time to be prepared to meet emergencies by furnishing water at an especially high rate for a short time.

These conditions appeared to be met by a large dug well which had the advantages of serving as a collecting unit and also providing the desired storage from which the water could be pumped more readily than directly from the ground. This well was constructed as a caisson with a cast-iron cutting edge and reinforced walls 18 in. thick. A reinforced concrete roof was made at about the former ground level and covered with 30 in. of earth, access being provided by a double covered manhole. A 4-in. air vent was also provided. (Figure 2.)

While the dug well was being constructed, four tubular wells were added to the system which now consists of fourteen 2½-in. tubular wells 25 to 35 ft. deep, connected to a 6-in. cast-iron suction main leading to the sand chamber in the pumping station. From the dug well an 8-in. pipe connects with the 6-in. suction main at the sand chamber.

As long as gates on both suction mains are kept open, the amount pumped from either source is determined by the hydraulic balance between the two halves of the system. It is obvious that the draft on the tubular wells is limited by the fact that there can be no great drawdown except as such drawdown also takes place in the dug-well; also that drawdown in the dug-well requires exhaustion of stored supply and takes time. To lower that water level by 5 ft. means the pumping of 18 000 gal. from storage in addition to the yield, which will be increased to a rate of 300 g.p.m. with the lowered level. The storage in such a well acts in a way analagous to a distributing reservoir and permits pumping for short periods at rates very much in excess of safe yields from the ground. Not only does the storage in the upper section in such a well prevent a drawdown which would create undesirable velocities of flow toward the wells, but when after continued pumping at high rates the accumulated storage is largely dissipated, the lowered level in the wells has been accompanied by a lowering of the ground water in the adjacent area and the establishment of more gradual hydraulic slopes, with the avoidance of high velocities.

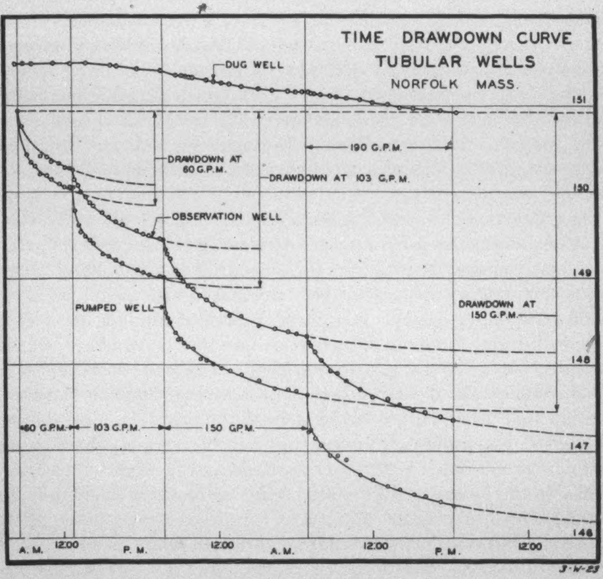


Fig. 3.

The flow into a well in a given material is dependent not upon the drawdown from the original static water level but upon the hydraulic capacity of the water-bearing stratum and the slope of the water surface. This slope may be measured by observing two wells, one being pumped, and one a few feet distant. Our experience has indicated that the loss of head between such points remains constant for a given pumping rate, even though the water level in both is lowered as pumping continues. This is illustrated in Figure 3, which shows how the time-drawdown curves of pumped well and observation well parallel each other for a given pumping rate.

We have tested this well field in several ways during the past year. Before selecting the location for the dug well, preliminary test wells were driven at locations determined as we proceeded. The best coarse water-bearing deposit being located, six wells were driven on what was proposed to be the location of the outside of the caisson, being carefully spaced in a regular hexagon, 14 ft. apart on a 14-ft. radius. An observation well was located in the center of the group, another about 2 ft. outside and others at irregular intervals. Our explorations had disclosed no free channel of communication between the old tubular well field and this new location, the former extending from 40 to 200 ft. easterly from the pump house and the latter being 400 ft. south westerly. The six wells were connected and given a short pumping test. Observation of water levels showed a response in each location to pumping at the other, a fact which had to be taken into consideration in our later tests. This evidence of communication made us sure that the pocket of coarse material that we found as indicated by borings was not a local deposit but was connected to larger deposits and could be expected to collect a large part of the underground flow of that valley.

On completion of the system, we tested the dug well alone, the tubular wells alone and the two fields together. In testing the dug well, we pumped with a portable pump directly from the well to a weir box, holding as closely to a constant rate as was practicable. Records of water levels were taken day and night, at regular intervals, during periods of pumping and recovery. The records during pumping seemed to confirm the theory of a straight line relationship between yield and drawdown. Certainly the flow into the well, or yield, equalled the difference between the rate of pumping and the loss of storage, and increased proportionately to the distance below the initial level. Levels taken during recovery also indicate a yield which increases directly in proportion to the drawdown, but at a slightly lower level. Presumably the lowering is due to the fact that recovery could only reach the initial level after a rain.

The difficulty with a yield-drawdown relationship, however, is that the plane from which drawdown is to be measured is subject to disturbing influences and is considerably affected by the pumping. In pumping at fixed rates from the tubular wells, we found that the water level continued to fall at decreasing rates but nevertheless with considerable rapidity for several hours. The flow into the wells, or yield, was equal to the pumping rate. The drawdown, measured from the initial level might be 1.15, 1.43, and 1.58 ft. at the end of one, two and three hours pumping, while the yield was constant. The rating curve, to which we refer later, shows a constant relationship between the yield and the slope toward a pumped well, as measured by the difference in water levels between adjacent wells.

Subsequent pumping and recovery tests, with the dug well and tubular wells connected by the suction main through which the water was free to pass not only during the pumping but also during the recovery, as indicated in Figure 4, show that recovery of storage in the dug well was hastened by flow from the tubular wells during the first part of the recovery period, and later was retarded by flow back through the suction main to the tubular wells and thence out into the ground storage. The restoration of water in the ground around the tubular wells, due to the natural repletion from the surrounding area, was thus augmented and the time of recovery shortened. These effects are also shown on Figure 6 which is discussed later.

We have previously referred to the relationship of the slope of the water surface or the drop in head between two points of observation, and the flow into the well or yield. Repeated observations at different pumping rates, each continued for a considerable time, showed that the cone of depression lowered as pumping progressed but did not appear to change its shape, at least at points near pumped wells. The water levels in a well being pumped and in an observed well 25 ft. away were lowered as the pumping proceeded, but maintained a constant difference as long as the pumping rate was unchanged. We show in Figure 3 a record of the water levels in these wells throughout the period during which four different pumping rates were maintained. Figure 5 is a rating curve showing the difference in level between these wells at the different pumping rates.

A confusion can easily exist as to what is meant by drawdown. The cone of depression is refilled by radial flow from outside its limits and by percolation downward. The downward percolation is due to water temporarily held in the interstices in the earth and lagging behind as the water table is lowered, and to rain on the area of the cone of depression. Many mathematical formulas have been evolved in the attempt to find some determination of yield, based upon assumptions as to the source of the water entering the cone of depression, as well as other assumptions of permeability and depth of the water-bearing stratum and its relation to the collecting well. It may be that the geology of other sections of the country permits the application of such formulas, but there appears to be so little uniformity or continuity to gravelly deposits in New England that formulas based on such assumptions can be very misleading.

The "rating curve" appears to establish a relationship between the adjacent water surface and the yield of the wells being tested and to do this independently of the duration of the pumping test. It is recognized that under some geologic conditions a lowered water surface may produce a marked change in hydraulic capacity of the porous stratum, but our observations did not show this to be the case at Norfolk. Additional tests under other conditions may fail to show this parallelism between the time-drawdown curves of adjacent wells, but we believe that such failure can only be a result of a change in hydraulic capacity of the water-bearing stratum and indicative of facts the engineer should know.

Each point on the rating curve represents a large number of observations of the difference in water levels while pumping at a fixed rate. The yield appears to increase directly with this difference in level up to a point beyond which it would probably prove undesirable as well as unprofitable to attempt greatly to increase the draft. It is probable that further increase

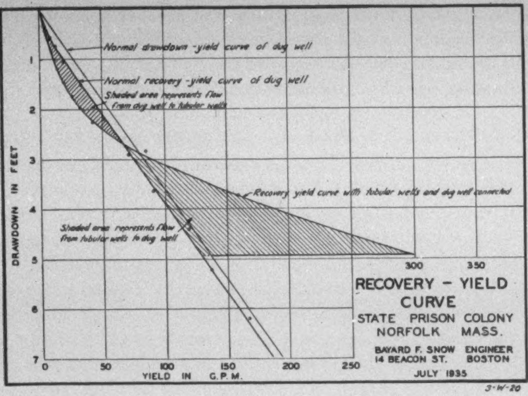

Normal drawdown-yield curve of dug well
Normal recovery-yield curve of dug well
Shaded area represents flow from dug well to tubular wells
Recovery yield curve with tubular wells and dug well connected
Shaded area represents flow from tubular wells to dug well
DRAWDOWN IN FEET
1
2
3
4
5
6
7
0
50
100
150
200
250
300
350
YIELD IN G.P.M.
RECOVERY - YIELD CURVE
STATE PRISON COLONY
NORFOLK MASS.
BAYARD F. SNOW ENGINEER
14 BEACON ST. BOSTON
JULY 1935
3-W-20

FIG. 4.

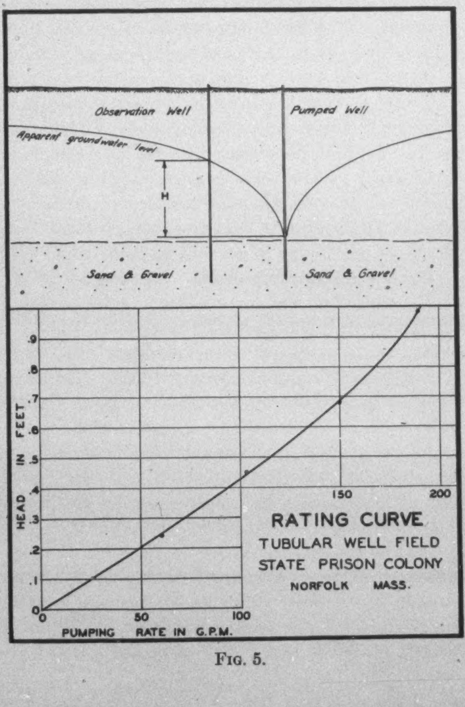

Observation Well
Pumped Well
Apparent groundwater level
H
Sand & Gravel
Sand & Gravel
HEAD IN FEET
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
0
50
100
150
200
PUMPING RATE IN G.P.M.
RATING CURVE
TUBULAR WELL FIELD
STATE PRISON COLONY
NORFOLK MASS.

FIG. 5.

in the steepness of slope toward the well, or difference in level between the points of observation, would result in small increase in yield. In other words, the rating curve appears to tend toward the vertical at a point corresponding to the limit of safe draft on the wells. In this case we found the curve started to break at about 12 g.p.m. per well and that there seemed little chance to increase the yield beyond 15 g.p.m.

The rating curve is also useful as a means of measuring the flow into the wells under conditions which prevent other measurements of yield. For example, the yield curve of the tubular wells, obtained during the pumping test on those wells alone, was used as part of the data for the diagram showing the effect of pumping from the combined system, (Figure 6), and resulted in a total which closely checked the Venturi rate.

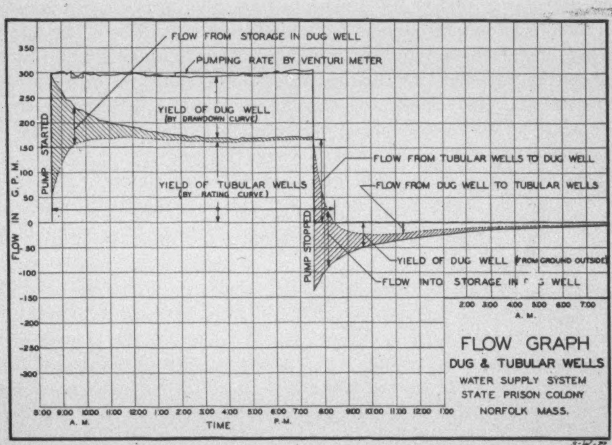


FIG. 6.

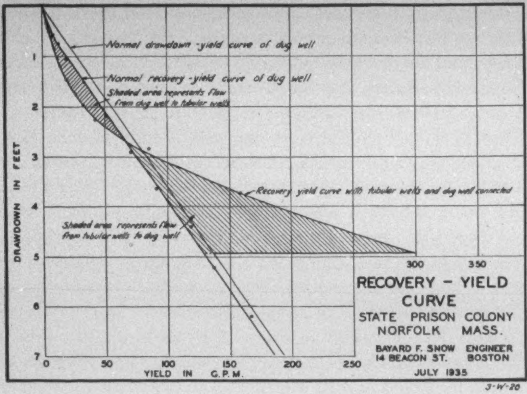
The time-drawdown curve appears to follow the general formula $D = K(1 - \log_e T)$

where D = drawdown from initial level, in feet

T = time from starting pumps, in minutes

K = a constant, dependent on rate, permeability, etc. (Under observed conditions and with above units, K varied between 20 and 76.)

We have not gathered enough data to determine general values of K, but the curve for any given conditions may be computed and extended, using observed values of D and T. The curve based on computed values compared very well with observed results.


Normal drawdown -yield curve of dug well
Normal recovery -yield curve of dug well
Shaded area represents flow from dug well to tubular wells
Recovery yield curve with tubular wells and dug well connected
Shaded area represents flow from tubular wells to dug well
DRAWDOWN IN FEET
1
2
3
4
5
6
7
0
50
100
150
200
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300
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YIELD IN G.P.M.
RECOVERY - YIELD CURVE
STATE PRISON COLONY
NORFOLK MASS.
BAYARD F. SNOW ENGINEER
14 BEACON ST. BOSTON
JULY 1935
3-W-20

FIG. 4.

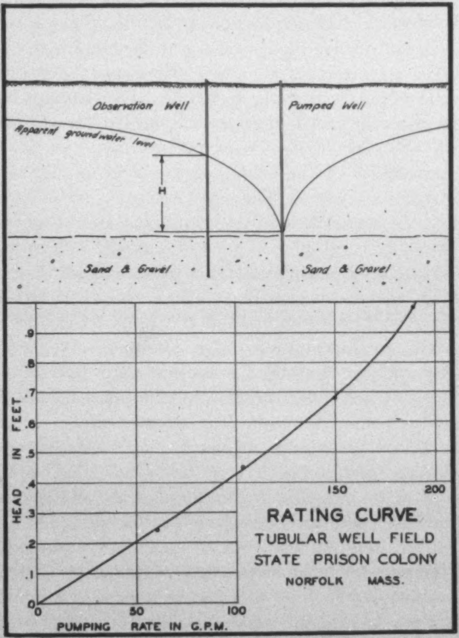
Observation Well
Pumped Well
Apparent groundwater level
H
Sand & Gravel
Sand & Gravel
HEAD IN FEET
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
0
50
100
150
200
PUMPING RATE IN G.P.M.
RATING CURVE
TUBULAR WELL FIELD
STATE PRISON COLONY
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FIG. 5.

in the steepness of slope toward the well, or difference in level between the points of observation, would result in small increase in yield. In other words, the rating curve appears to tend toward the vertical at a point corresponding to the limit of safe draft on the wells. In this case we found the curve started to break at about 12 g.p.m. per well and that there seemed little chance to increase the yield beyond 15 g.p.m.

The rating curve is also useful as a means of measuring the flow into the wells under conditions which prevent other measurements of yield. For example, the yield curve of the tubular wells, obtained during the pumping test on those wells alone, was used as part of the data for the diagram showing the effect of pumping from the combined system, (Figure 6), and resulted in a total which closely checked the Venturi rate.

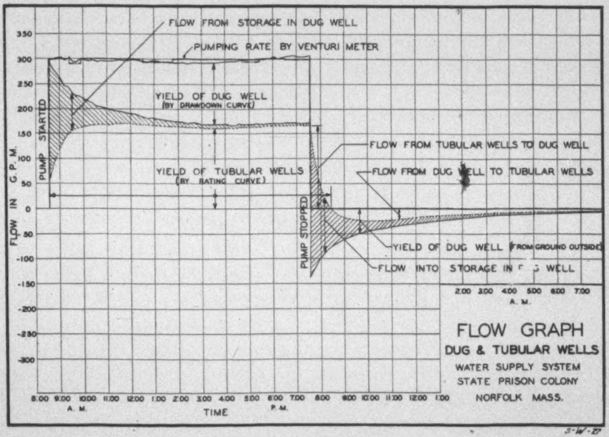

FIG. 6.

The time-drawdown curve appears to follow the general formula

$D = K(1 - \log_e T)$

where D = drawdown from initial level, in feet
T = time from starting pumps, in minutes
K = a constant, dependent on rate, permeability, etc. (Under observed conditions and with above units, K varied between 20 and 76.)

We have not gathered enough data to determine general values of K, but the curve for any given conditions may be computed and extended, using observed values of D and T. The curve based on computed values compared very well with observed results.

The third part of the test consisted of pumping from the combined system and watching the recovery. The discharge from the station was measured by Venturi meter and was obtained from three sources: yield of the tubular wells, yield of the dug well and reduction of storage in the dug well.

Figure 6 shows the effect of this test. The first half of the diagram shows the quantities from each of the three sources and a comparison of their sum with the metered discharge. The second half shows the same effect discussed in connection with Figure 4.

The combination of storage in the dug well with the yield of the combined fields meets the desired conditions; storage to permit heavy draft for short periods, if desired for fire protection, plus an increased yield. A reservoir would provide storage but would have to be filled. The dug well provides a self-filling reservoir together with additional ground storage immediately adjacent. Ordinarily we expect a depletion of about 4 ft., but we can draw 10 ft. lower with existing equipment. Aside from increased yield, which at the lower level becomes over 500 g.p.m., the storage between these levels is 40 000 gal., available for any emergency.

The caisson-type dug well was constructed by James A. Munroe of North Attleboro. The B. F. Smith Co. did the exploratory work. Mr. John W. Greenleaf assisted the author in the tests and preparation of data for this paper.

PROCEDURE
IN DEVELOPING A GROUND WATER SUPPLY BY SHALLOW DRIVEN WELLS.

BY RALPH W. HORNE.*

[*Read September 19, 1935.*]

The sequence of the important steps in developing a ground water supply by shallow driven wells is:

(1) To estimate the maximum rate of draft which the wells must be able to yield.

(2 To select a site adapted for the installation of the driven well system.

(3) To install a system of test wells.

(4) To conduct a pumping test of the wells.

(5) To estimate the adequacy of the well site for furnishing the required draft of water.

(6) To install additional wells and construct a permanent system of driven wells and suction piping, incorporating in the system all test wells which are suitable for the purpose.

Description of Shallow Driven Well. A shallow driven well, as referred to in this paper, consists of an open-ended pipe driven into the ground, with the assistance of washing as necessary, until it penetrates a water-bearing stratum of material sufficiently permeable to permit the water to percolate through the stratum without undue resistance and rise in the well. A shallow driven well, as commonly used in New England for municipal water works, may vary in depth from about 20 ft. to about 60 ft. and generally is 2½ in. in diameter. The lowest section of the well pipe, say the bottom 18 in. to about 3 ft., is perforated with holes about ⅜ in. in diameter and spaced about 2 in. apart, the length of the perforated section of pipe varying with the thickness of the water-bearing stratum encountered. The normal safe yield of such a well may vary from 5 to about 50 g.p.m., depending upon the size of the well and the permeability of the water-bearing stratum. If the water-bearing stratum consists of very fine material, it may be necessary to install a well strainer at the bottom of the well as a precaution against drawing an excessive quantity of the fine material into the well and clogging it. The general arrangement of such a well is shown in Figure 1.

Behavior of Ground Water Table Adjacent to Driven Well. When water is pumped from a shallow driven well the ground water level at the well and in the vicinity of the well is lowered below the normal ground water level as indicated in Figure 1. The amount of this lowering of ground water level is termed "draw-down." The shape taken by the water surface within the area of draw-down is termed the "draw-down curve," and the perimeter of the area within which the draw-down of water level takes place is termed the "circle of influence." Depletion of the volume of water inside the limits of the draw-down curve indicates a corresponding reduction in the volume of water in ground storage; the maximum rate at which water will continually flow into a driven well, during pumping, from outside the limits of the draw-down curve is the maximum "safe yield" of the well. The maximum rate at which water can be pumped from a shallow driven well will have been reached when the level of the water table at the well has been drawn down to the upper holes or perforations in the well pipe. At this level, air will be drawn through the soil and through the well pipe perforations into the well, thereby breaking the suction in the well and interrupting the draft of water from the well.

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*Partner, Fay, Spofford and Thorndike, Consulting Engineers, Boston.

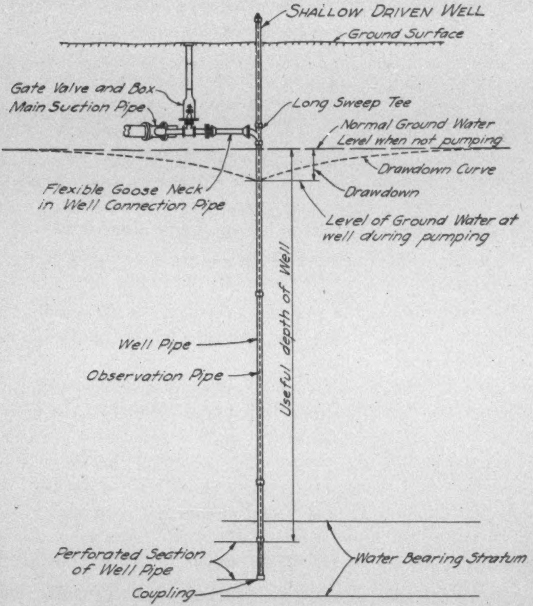

SHALLOW DRIVEN WELL
Ground Surface
Gate Valve and Box
Main Suction Pipe
Long Sweep Tee
Normal Ground Water Level when not pumping
Drawdown Curve
Drawdown
Flexible Goose Neck in Well Connection Pipe
Level of Ground Water at well during pumping
Useful depth of Well
Well Pipe
Observation Pipe
Perforated Section of Well Pipe
Water Bearing Stratum
Coupling

FIG. 1.— GENERAL ARRANGEMENT OF SHALLOW DRIVEN WELL.

Yield of Group of Shallow Driven Wells. Within the limits of accuracy which it is practical to attain in estimating ground water yield, the general ground water table surrounding a group of shallow driven wells may be assumed to behave as in the case of one large well located at the center of effect of the group of wells. It is essential in planning the development of a ground water supply by a group of shallow driven wells to ascertain as accurately as possible the greatest rate at which water can be pumped continuously from the wells without exceeding the maximum safe draw-down of the ground water level, or without drawing an excessive quantity of material from the water-bearing stratum into the wells; this maximum safe rate of pumping from a group of wells is taken as the maximum "safe yield" of the wells.

By means of a pumping test it is possible to measure the amount of draw-down of ground water level corresponding to different rates of pumping from a group of shallow driven wells, and by using these data the draw-down for other rates of pumping may be approximated and also the pumping rate corresponding to the maximum safe draw-down. These approximations may be made graphically from a diagrammatic record of draw-down and yield. The pumping test should be continued for each pumping rate until a stage of practical equilibrium of ground water level is reached. It is possible by taking regular observations during a pumping test to ascertain whether a condition of equilibrium of ground water can be reached during continuous pumping at a desired maximum rate of daily draft and thereby to establish the ability of the ground water basin to yield the desired maximum daily volume of water. In planning a new system of driven wells the contemplated normal daily pumping period frequently will not exceed 8 hours, and a continuous 24-hour pumping test will therefore permit the pumping of the desired maximum daily volume of water from one-third as many test wells as the number of pumping wells required for the permanent installation. To ascertain the maximum safe yield directly from a well test, the test should be conducted under the most critical conditions of ground water stage, rainfall and season; other important factors which affect ground water yield such as porosity and size of water-bearing material and effect of surface tension will have their influence reflected directly in the observations taken. Conclusions as to ground water yield which are based on a continuous pumping test carried to a stage of practical equilibrium of ground water are doubtless more reliable than conclusions reached by any other method.

Frequently lack of funds or other conditions incident to a well test will not permit the continuance of the test until a point of equilibrium of ground water level is reached, and in such cases a rough estimate of yield may be made by calculating the total volume of pumpage during the test and subtracting therefrom the volume of water estimated to have been obtained by depletion of ground storage, the net amount representing the yield. Such estimates should be based on observations of draw-down, taken during the test. In estimating the volume of water which represents depletion of ground storage the total volume inside the limits of the draw-down curve should be corrected for the factors of percentage porosity and capillary attraction. After applying these corrections, it may be found that the actual volume of depletion of ground water storage will not exceed 5 to 10 per cent. of the total volume within the draw-down curve. Estimates of the volume of water drawn from ground storage are uncertain because the shape of the draw-down curve and the extent of the circle of influence are difficult if not impossible to ascertain. At the outset of a well test most of the water pumped is drawn from ground storage, but as the test continues more and more of the pumpage is derived from yield. If a well test is continued for 6 or 7 days or more and the site is at all favorable for a driven well system it is reasonable to expect that about 80 per cent. or more of the total pumpage during the test will be derived from yield.

The use of empirical formulas to estimate draw-down and yield for a group of driven wells has been given much consideration, and such formulas may be helpful in making estimates of these factors. The general formulas which have been developed may be applied to a specific well system if a well test has been conducted and a stage of ground water equilibrium has been reached for a known pumping rate. Measurements of draw-down in test wells and in observation wells placed at various distances from the center of effect of the test wells may be substituted in the general draw-down formulas, and a formula applicable to the particular well system in question may be derived to show the relation between draw-down and yield. The formulas are intended to take account of the effect of porosity and size of water-bearing material and may be quite conveniently used if it is assumed that the effect of these factors is constant both for the rate of draft at which the test was conducted and for other rates of draft as well; such an assumption frequently will not be reliable for geological conditions found in New England.

In making estimates of the yield of a group of driven wells, based on observations taken during an extended pumping test, correction should be applied for all rainfall during the test.

Of the several factors which have distinct bearing upon the yield of a ground water supply, it should be recognized that some are bound to vary with the season of the year and some will even vary between the location of individual wells of a group. These factors include the porosity and size of the water-bearing material, the normal ground water level and the water temperature.

A knowledge of the extreme fluctuations in normal ground water level throughout the year and throughout a cycle of dry and wet years is quite essential, but published records of these data are meager. From a few available records of fluctuations in normal ground water level in New England it appears that a fluctuation of 3 to 5 ft. might readily be expected between high and low stages of ground water during the year. It is practically impossible to tell what the variation in all pertinent factors will be for different locations and different seasons of the year; therefore estimates of yield always should be conservative and allow a liberal factor of safety.

Data to be Secured in Making Well Test. At the outset of a well test it is quite uncertain whether the test can be continued at desired pumping rates until a condition of ground water equilibrium is reached, and it is equally uncertain whether a severe rain storm will not be experienced which will materially alter if not spoil the results of the test. Furthermore, there is always the possibility of a breakdown during a test. In consequence of the various possibilities of interference with the satisfactory conduct of a test, sufficient observations should be taken during the test so that estimates of the safe yield of the well site may be made by any or all of the methods previously enumerated.

In making a well test, data should be obtained as to the rate of pumping from the group of wells, the location of each well used for test and observation purposes, the elevation of the ground water table before pumping commences as shown by the water level in the wells, fluctuations of the ground water table during the pumping test, draw-down of water level in the wells when a stage of ground water equilibrium is reached, rate of recovery of ground water table after pumping is stopped, useful depth of the wells, rainfall during the pumping test and any effect upon the flow of nearby streams due to the pumping test or to rainfall.

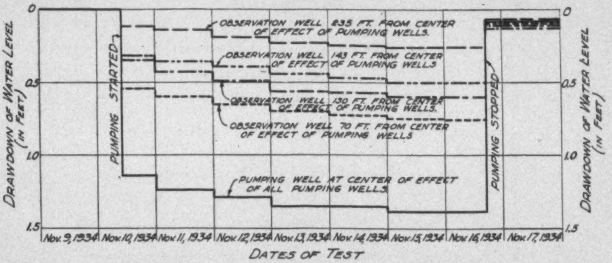


FIG. 2.—OBSERVATION OF GROUND WATER LEVELS DURING TEST OF SHALLOW DRIVEN WELLS AT STERLING, MASS.

An average pumping rate of 10 g.p.m. per well from 12 wells was maintained continuously during the test. Rainfall during the test was negligible.

All records of elevations of ground water level and other elevations pertaining to the well system should be referred to a common datum established in advance of commencing the test. Observation of ground water levels both in observation wells and pumping wells should be taken regularly several times each day during the test.

A graphical record of some of the observations of ground water levels taken during a well test is shown in Figure 2, by reference to which it will be noted that the greatest draw-down of the ground water table took place in the pumping well, this well being located approximately at the center of effect of pumping on the group of wells. It also will be noted that the draw-down in water level measured in the observation wells decreased with increased distance of the individual observation well from the center of effect of the pumping wells; this is typical of ground water draw-down during pumping. It will be noted that the duration of the test was carried practically to equilibrium of ground water level and that when pumping stopped the ground water level recovered rapidly, practically returning to the level prior to the commencement of the test, which indicates that the rate of pumping did not exceed the safe yield of the group of driven wells.

It is indicated in the preceding pages that a curve showing diagrammatically the relation of draw-down to yield may be prepared from measurements of ground water draw-down for several known rates of pumping and used to predict draw-down for other pumping rates. Such a curve is shown in Figure 3. The wells to which Figure 3 relates are dug wells rather than driven wells, but insofar as the relation of draw-down to yield are concerned the same general principles are applicable to each type of well. Figure 4 also presents a draw-down curve, but this curve was calculated from empirical formulas using data obtained from observations taken for one rate of pumping from a group of driven wells. The curves shown both in Figure 3 and Figure 4 indicate that draw-down varies approximately in proportion to the rate of pumping.

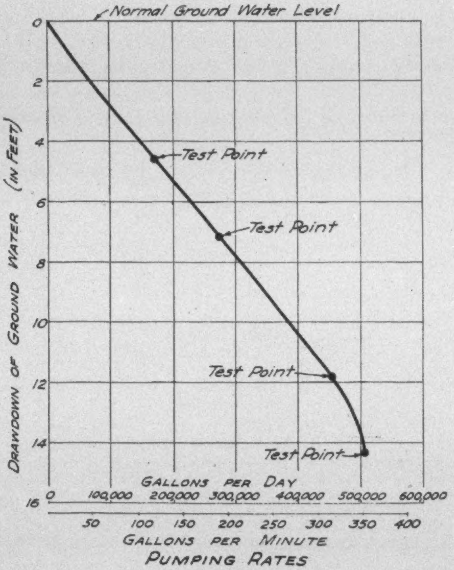


Fig. 3.— Yield of Dug Well at Winchendon, Mass.

Steps in Developing a System of Shallow Driven Wells. When proceeding to develop a ground water supply by shallow driven wells, it is essential as in the case of any water supply to estimate the maximum daily draft of water which the supply must furnish, in order to approximate both the extent of watershed area which should be tributary to the driven well system and the number of wells needed. The safe yield of a watershed and the necessary number of wells can be accurately ascertained only from an actual test of wells driven within the watershed, but for a rough estimate of the watershed area needed the rate of yield per square mile of drainage area may be estimated, and it may be assumed that each well can safely be pumped at a rate of about 10 g.p.m.

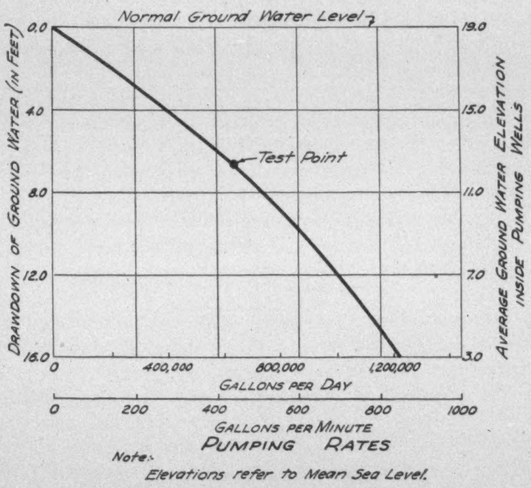
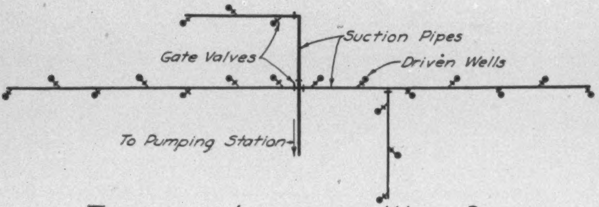


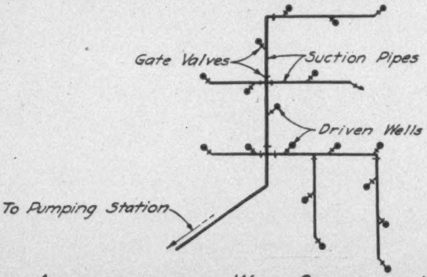
FIG. 4.— YIELD OF DRIVEN WELLS AT WAREHAM, MASS.
Formula: $Q = 1021 - 1.395h^2$
Q = g.p.m.
h = 27 ft. (useful depth of well) minus drawdown in ft.

From a study of the topographic maps of the United States Geological Survey, possible well sites with sufficient tributary watershed area may be selected, and by making a field reconnaissance of such possible sites, the site where surface indications are most favorable for a driven well system may be chosen. To be favorable for a driven well system, sites should be suitable for installing a sufficient number of wells in logical arrangement and should indicate deposits of sand and gravel and the absence of excessive deposits of vegetable matter from which the water might derive a high content of iron or other unfavorable constituents.

After selecting a site or sites to investigate for installation of a permanent well system, a tentative layout of wells should be adopted which appears to fit the site according to surface indications. The test wells should be driven in such sequence that each will furnish information as to the suitability of the site. The first well driven may properly be located near the center of the tentative well layout, and the second and third wells should be driven at opposite extremities of the layout. If the wells at the extremities are successful, intermediate wells about midway between the central and extreme wells should be driven, and if they, too, are successful, it may be assumed that the well layout can be installed approximately as planned. If any of the wells are unsuccessful they may be of value as observation wells and if so should not be withdrawn until the pumping test has been conducted. If the initial wells do not prove to be successful and it still is desirable to use the site, a new tentative layout of wells to fit the site should be made and additional exploration wells driven.



TENTATIVE LAYOUT OF WELL SYSTEM



FINAL ARRANGEMENT OF WELL SYSTEM AS INSTALLED

FIG. 5.— DRIVEN WELL SYSTEM AT GEORGETOWN, MASS.

The layout of a driven well system as finally accomplished often will differ materially from the initial tentative layout made before the wells were driven. Figure 5 shows the relative arrangement of the tentative layout of a driven well system as compared with the layout of the wells finally installed.

As an individual test well is developed into a satisfactory well, it should be thoroughly pumped until the water is acceptably clear, and samples of the water from representative wells should be analyzed for chemical character. If the water shows an unfavorable content of constituents such as iron, manganese, carbon-dioxide and pH, it may be advisable to test a new well site, and it certainly will be advisable to compare the cost of an alternate well site, even though less favorably located, with the cost of a water treatment plant.

Test wells should be made up of genuine wrought-iron pipe or of material equally durable, and each joint of the well pipe should be tightly made. Red lead may be used to coat the pipe threads at the joints. The assembly of the test wells should be such as to produce an air tight well, because the test wells, if successful, should be made a part of the permanent well system, and all joints of the permanent well system should be made air tight.

During the driving of test wells, careful records should be made of the materials encountered and the depth of reaching freely circulating ground water. These observations should be preserved together with a record and samples of the material. Elevations of each point of change in stratum, referred to a common datum, should be recorded together with the elevations of the bottoms of the well pipes and of the upper perforations or holes in them.

Development of an individual driven well relates to the removal of the finer particles of the materials adjacent to the well pipe from their natural location by pumping them out through the coarser adjoining materials and discharging them through the well. A properly developed well is one in which the larger materials only are left immediately adjacent to the well and in which the surrounding material is graded by the pumping process so that the finer materials are all at greater distance from the well pipe. This process of developing a well by pumping out the finer materials which immediately surround it and grading the remaining material produces relatively large voids immediately adjacent to the well and progressively smaller voids as their distance from the well becomes greater.

By this arrangement of voids the total void area through which the water must pass in approaching a well is far more constant than in the natural arrangement of the material, and a more uniform velocity of flow toward the well is accomplished, resulting in a less abrupt draw-down of ground water surface near the well and a safer "working depth" of well.

In developing a well, the use of a diaphragm pump or pump of this general type which produces a surging action when operated is far more beneficial than the use of a centrifugal pump which draws the water from the well with a more regular flow. The surging action tends to loosen and dislodge the smaller particles of material from the larger particles and by so doing increases the void capacity in the vicinity of the well. Wherever possible the development of a surrounding strainer of natural material is to be preferred to the use of an artificial well screen.

It is important to have accurate measurements of the lowering of the water level in a pumping well during a well test. Such measurements may be obtained by attaching a vacuum gage to the top of a well, or where records of the water level in a number of pumping wells are desired it may be more economical to insert in the wells a small observation pipe carried nearly to the bottom of the well and sealed from the well pipe so that the top of the observation pipe may be left open for measuring purposes without interference with the suction within the well pipe itself. Such an arrangement is indicated in Figure 1.

For the pumping test of a group of wells, the pipe connecting each test well with the suction main should be provided with a gate valve, so that each individual test well may be shut off from the well system if desired and in order that the rate of draft of water from each well and the resulting draw-down of water level in each well may be closely regulated. It is desirable that the draw-down in all wells be kept practically uniform as a precaution against an excessive rate of draft from wells located nearest the pump and consequent damage to the natural strainer developed in the material immediately surrounding the well pipe.

All temporary suction piping set up for testing should slope upward from each pumping well to a sand chamber adjacent to the pumping equipment. By this arrangement, any air which may find its way into the wells or suction piping will be exhausted from the mains rather than pocketed to become a hindrance to pumping. Any material drawn from the wells during pumping will be collected in the sand chamber and retained there rather than entering the pumps and damaging them. Suction mains for the pumping test generally may be placed above ground.

For temporary pumping test facilities, either a displacement pump or a centrifugal pump is satisfactory, and the most popular sources of power for operating test pumps at the present time are either gasoline engines or electric motors. An electric motor is apt to be more reliable and requires less attention than a gasoline engine. No doubt the simplest and most reliable test pumping equipment is an electric motor driven centrifugal pump.

The water pumped from the wells should be discharged through a device for accurately measuring the rate of pumping, and for this purpose the use of a weir box will give very satisfactory results. Special precautions should be taken that the water discharged from test pumps shall not find its way back to the vicinity of the wells but shall be discharged at a point where it will escape readily without affecting the ground water table at the well site.

If estimates of the safe yield of a well site based on a well test show that an adequate supply of water can be secured, additional wells should be driven which, together with the test wells, will constitute a permanent driven well system. The test wells should have been so located that there will be an opportunity for driving the additional wells within the area explored by the test wells and adjacent to them. The proper well spacing will have been indicated in driving the test wells and by the results of the well test. Generally the wells should be spaced at least 25 ft. apart, and a spacing as great as 40 ft. or more may be found advisable. By placing the wells at the corners of equilateral triangles whose sides are the length adopted for the well spacing, the most intensive development of a well site may be accomplished.

Each permanent well should be joined to a system of permanent underground suction piping by installing a long-sweep tee in the well pipe at the proper elevation and connecting the horizontal run of the tee to the suction pipe by means of a well-connection pipe of the same diameter as the well. Each well-connection pipe should be provided with a flexible gooseneck of heavy lead pipe or copper tubing and a gate valve. A gooseneck is essential to give flexibility in the well-connection pipe and allow for any movement of the well. A gate valve is important to permit the rate of draft from the well to be regulated and permit the well to be shut off from the system for testing and for cleaning in case it becomes clogged.

The permanent suction piping and well connections should be designed for low friction losses and laid carefully with air-tight joints, the piping sloping upward continuously from each well to the pumps. The suction main and any branch suction pipes leading from the main should be provided with gates, so that if a stretch of suction pipe develops leaks or other trouble it can be isolated for repair without placing the entire system of suction pipes and wells out of service. All gate valves installed should be air tested at the factory and the valves on well connection pipes should not be opened until after they have been installed and the entire suction main system has been tested for tightness. The suction main should be made practically air tight and should be tested for tightness by air under pressure of about 25 to 50 lb. per sq. in. A leakage of about ½ to 1 lb. per linear foot of pipe joint per day should be acceptable. After suction mains have been tested, the portions of the well connections which lie beyond the well-connection valves and also the wells themselves may be tested for leakage under a lesser air pressure by building up enough air pressure in the well system to force the water level in the wells nearly down to the upper perforations of the well pipes. This test may involve a pressure of about 8 to 20 lb. per sq. in., depending on the depth of well and ground water level.

A permanent sand chamber should be installed in the suction main so that the water drawn from all wells will pass through the sand chamber before entering the pumps and the reduced velocity of flow through the sand chamber will cause sand and other material drawn from the wells to be retained in the chamber instead of entering the pumps and damaging them by scoring pump cylinders or wearing impellers and cases.

When the system of permanent wells, suction piping and appurtenances has been completely installed and tested for tightness, the entire installation should be subjected to pumping for a sufficient period to insure that all features are properly adjusted. The opening of well-connection valves should be set to produce a practically equal draw-down in each well. Measurements should be made in each well of the depth of core which has formed in the well, and if the core is such as to impede the yield of the well it should be removed and if necessary a strainer installed.

The entire work of installing the test wells, making the well test, installing the additional wells and all suction piping and appurtenances should be entrusted to one contractor or one individual thoroughly experienced in work of this nature in order that responsibility for results shall not be divided and that the best possible results may be secured. The services and practical knowledge of an experienced well driver are invaluable throughout the entire procedure of developing a driven well system, and if employed in conjunction with the services of a technically trained man to lay out the well system, supervise the testing and interpret the results of the tests, the most satisfactory results ought to be secured.

DETERMINING
THE YIELD AND QUALITY OF WATER FROM TUBULAR WELLS BY MEANS OF THE WELL RATER AND SAMPLER.

BY PAUL F. HOWARD.*

[*Read September 19, 1935.*]

It is oftentimes desired and of importance to ascertain the quantity and quality of water yielded by an individual driven well connected to other wells of a water system. Experience has shown that analyses of samples of water taken from individual wells by means of a hand pitcher pump give false and meaningless results especially in relation to the iron content. Likewise the yield of an individual well by means of a hand pump furnishes but little if any information as to the yield of the individual well when ganged together into a common system.

Whitman & Howard were engaged, some two years ago, to investigate a water supply of the city of Attleboro, Mass. from about 90 driven wells. During the course of the work, it became desirable to determine the yield of each individual well and the iron content of the water from each individual well under normal operating conditions. This was done by a device which we have called a "well rater and sampler" (Figure 1). The device was connected to the top of the well by a 2½-in. wrought-iron pipe about 2½ ft. long. At this point a 1¼-in. centrifugal pump was connected by the proper fittings and discharged through a 2-in. pipe. On the suction pipe a hand pump was attached to prime the pump. A 2-in. orifice flow meter was inserted in the discharge line, and by means of a manometer the rate of flow was determined. The amount of the draw-down of the well when connected to the well field was determined by means of a mercury U-tube connected to a small tube attached to the well cap, the tube extending into the well to a depth sufficiently great so that the end was at all times below the level of the water outside of the well. Before the well rater and sampler was connected to the well, the permanently installed valve on the suction line was closed. After the device was connected, this valve was opened and the well was observed under actual working conditions, *i.e.* while it was being pumped along with the other wells by the large pump in the pumping station, the draw-down being observed by the manometer connected to the tube in the well. Again the permanently installed valve was closed and the centrifugal pump started. The quantity pumped was controlled by a valve on the discharge line. As the discharge increased the draw-down increased, producing a deflection on the manometer. When the manometer reading was the same as under actual working conditions, as just described, the yield of the well was the same. The quantity being pumped was determined by observing the deflection of the flow manometer. The results represented the actual amount of water that the well was contributing to the field as a whole. Samples of water for analyses were taken at the point of discharge. By careful operation of the valve at the discharge end of the pipe, the yield of the well was brought gradually up to the original yield thus avoiding higher velocities than usual or ordinary in the pipe well. Any excess velocities would, of course, free scale, rust and other matter and give false samples. The flow manometer in this particular instance was connected to the 2-in. orifice flow meter. The liquid used to determine the differential pressure can be of any specific gravity desired depending upon the rate of

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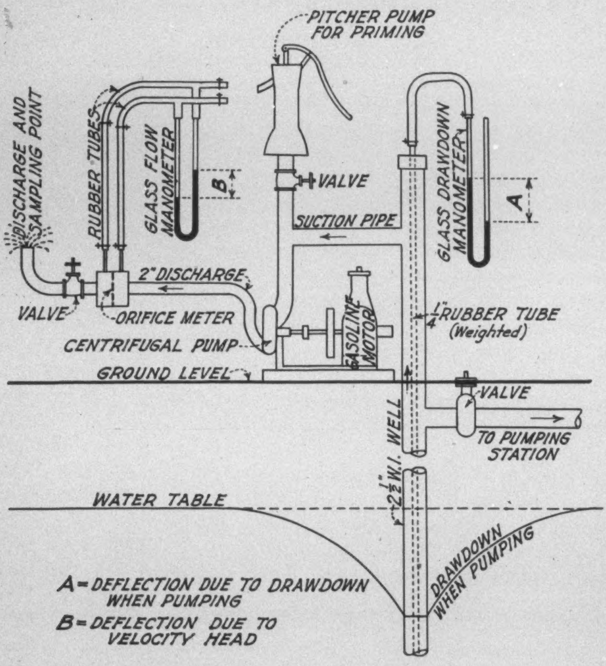
*Of Whitman and Howard, Civil Engineers, Boston, Mass.


PITCHER PUMP FOR PRIMING
DISCHARGE AND SAMPLING POINT
RUBBER TUBES
GLASS FLOW MANOMETER
B
VALVE
SUCTION PIPE
GLASS DRAWDOWN MANOMETER
A
2" DISCHARGE
VALVE
ORIFICE METER
CENTRIFUGAL PUMP
GASOLINE MOTOR
1/4" RUBBER TUBE (Weighted)
GROUND LEVEL
VALVE
WELL
TO PUMPING STATION
2 1/2" W.I.
WATER TABLE
DRAWDOWN WHEN PUMPING
A = DEFLECTION DUE TO DRAWDOWN WHEN PUMPING
B = DEFLECTION DUE TO VELOCITY HEAD

WELL RATER AND SAMPLER

FIG. 1.

flow to be measured. The most common is mercury for high flows and carbon tetrachloride, specific gravity 1.60, for low flows.

One side of the mercury U-tube was connected to the tube in the well and filled with water from the surface of the mercury to the water level in the well, care being taken to remove all air. The other side of the U-tube was left open to the atmosphere.

The following specific example will serve as an illustration. After the well rater and sampler had been properly set up and connected to a well, the mercury U-tube was connected to the tube in the well. There was an initial deflection of mercury of 3 in. which represented a water column of 40½ in., the distance from the water table to the mercury surface of the U-tube. After an equilibrium had been reached the well was connected to the field and the mercury in the U-tube deflected an additional amount corresponding in general to the distance the water table dropped outside of the well and specifically to the drop in pressure in the well. In this case the total deflection was 4¼ in., or a difference in deflection of 1¼ in., which equals 17 in. of water or the draw-down of the well. The well was then shut off from the other wells and the small pump started. The discharge valve on the pump was then opened slowly increasing the yield of the well until the draw-down deflection of mercury showed 4¼ in. After this point was reached, the flow manometer was observed to have a deflection of 1⅝ in. of mercury, which on this meter represented a flow of 20.1 g.p.m.

The yield of the various wells in relation to the draw-down was plotted on arithmetic paper, and the yield of each well was found to be directly proportional to its draw-down. The yield of the various wells varied from 1 to 25 g.p.m. and the draw-down varied from 5¼ to 26 in.

This device has been made use of in installing new driven well fields. By its use we have been able to predict reasonably well the draw-down or vacuum to be expected in a system of driven wells and to eliminate wells which have a low yield in relation to the drawdown. Also with open-end wells, it has been possible to determine at what yield a well will throw sand and thus to prevent the filling up of wells by sand.

GEOLOGIC FEATURES IN NEW ENGLAND GROUND WATER SUPPLY.

BY KIRK BRYAN.*

[*Read September 19, 1935.*]

The importance of ground water in water supply is difficult to evaluate because most installations are small and, being relatively permanent, become such intimate parts of the cultural landscape as to escape notice. Mr. Kingsbury† has, however, given us interesting estimates of the large part of the population dependent on wells and springs. At present there are two tendencies one decreasing and the other increasing the use of ground water. Urbanization which has been going on steadily in New England since 1840 leads to pollution and abandonment of wells and springs in and near the cities and to the installation of public supplies mostly derived from surface waters. On the other hand increasing facilities for rapid and individual transportation by automobile are extending the suburbs of all cities. This diffusion of the population, 20 to 50 miles from the center of cities puts an unbearable burden on the central supply system. Each house, therefore, acquires a water supply independent of others and thus there is a constantly increasing number of wells in the suburban zones. Smaller villages near large centers are growing and require public supplies. As many of these localities are more or less surrounded by lands held by larger communities, they turn to ground water.

Two General Sources of Ground Water. In New England the generally hard and crystalline bed rock is covered by a thin but irregular mantle of glacial deposits. Small supplies adequate for single houses may be obtained from wells drilled into the rock. Larger supplies, must, however, be obtained from the water-laid portions, sand and gravel, of the glacial drift.

The drilled well extending down into the bed rock has numerous advantages from a sanitary standpoint. Pumped by a modern installation to a pressure tank with automatic control, it is ideal for the isolated household. The yield is generally small, as the well draws only from the open cracks or joints of the rock. These cracks are fairly numerous and open near the surface but decrease in number and in their openness downward. Generally the number of joints is so small below 250 ft. that it is inadvisable to drill below that depth. There are, however, exceptions to this rule and there are a few wells of considerable depth and of large yield. Yet deep drilling in the crystalline rocks of New England cannot be advised.

For larger supplies the stratified drifts or sand and gravel deposits left by the retreat of the glaciers are our principal dependence. These deposits absorb water readily from rain and snow and yield water readily to wells. So far as their internal composition is concerned, they are ideal ground water reservoirs. However, the topography of New England is such that these deposits are generally confined to narrow stringers along valley bottoms and consequently have relatively small volume and no great continuity. Each body of sand and gravel acts as a more or less independent ground water reservoir whose hydrologic characteristics must be independently determined. Thus there is put on engineers and geologists a considerable burden. It is impossible to generalize too widely. Because one town has obtained satisfactory quantities from a bed of sand and gravel, it does not follow that a town four or five miles away will be equally fortunate. Each will draw from a different body having unlike opportunity to obtain water, unlike capacity for storage and unlike characteristics in yield.

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*Associate Professor of Physiography, Harvard University, Cambridge, Mass.

†See preceding paper in this issue of the Journal.

The routine mapping of sand and gravel deposits, some of which are adequate reservoirs of ground water has been recently completed for Maine* and Connecticut.*

Here are set forth in a general way the distribution of stratified drift, sand, gravel and clay so that the important ground water reservoirs can be readily found. I do not wish to imply that more detailed maps such as have been prepared for parts of Connecticut are not advantageous.† Nevertheless these generalized maps enable us to visualize the conditions found generally in New England. The sand and gravel deposits usually occur in the valleys and widen and thicken toward the sea coast. Thus one of our larger areas lies in southeastern Massachusetts and in Rhode Island.

Need for Further Investigations. Our knowledge of the bodies of sand and gravel in New England is gained by inspection in the field and by actual tests with wells. In developed or partly developed areas, such as the well-fields of some of our cities, the knowledge gained is detailed and precise. But this knowledge has been obtained by costly trial and error and is not directly applicable to other bodies of sand and gravel. It is obvious that more detailed geologic study of these ground-water reservoirs should be made. There should exist a clearcut well-defined geologic history of each locality in which the origin of each ground-water reservoir is clearly set forth.

It is my purpose to outline the general theory of the formation of sand and gravel bodies in New England and to point out the bearing of some new ideas regarding the glacial history on the distribution and character of these bodies.

Sand and Gravel Formed as a Result of Glaciation. The great ice-caps of the Pleistocene covered North America four successive times. In general the ice-covered area includes all of the United States north of the Ohio River and east of the Missouri River. This great area is the most densely settled and most prosperous part of the country in which more than 70 per cent.

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*Leavitt, N. W. and Perkins, E. H.; Glacial Geology of Maine, vol. II, Maine Technol. Exper. Station Bull. 30, 1935.

Flint, F. R.; Glacial Geology of Connecticut: Conn. Geol. and Nat. Hist. Survey Bull. 47, 1930.

†U. S. Geol. Survey Water-Supply Papers No. 374, 397, 449, 466, 470, and 540.

of the Federal Revenue arises. Thus the story of those ice sheets is of intense interest from many economic viewpoints.

Each ice sheet scraped the rocks on which it lay producing large quantities of débris which were dumped at its edge as unsorted masses of till or boulder clay or left when the ice sheet melted as a thin veneer of till — the so-called ground moraine. But the ice melted each summer and streams of water issuing from the ice carried out large quantities of this débris which were laid down as the stratified drift. Various types of this stratified drift occur. Outwash plains were built in front of the ice, kames on the border, eskers under the ice or at least within cracks in the ice. Fine clays and silts were also deposited in lakes and terraces of gravel formed as beaches by lakes and seas.

Now the till and stratified drift of a single ice sheet were deposited in a more or less single episode. The ice sheet began to form in Canada and extended southward each year until it reached its maximum size. The sand and gravel laid down in front of it generally were destroyed by its advance. After remaining at its maximum extent the ice retreated either slowly or in stages and during this process the stratified drift was preserved. However, all the materials were deposited in a comparatively short time.

The four great glaciations were, however, separated by long intervals during which the region enjoyed a climate milder than that of the present. The deposits of the older ice sheets were thus weathered much more than later ice sheets. We have therefore a criterion, although not an infallible

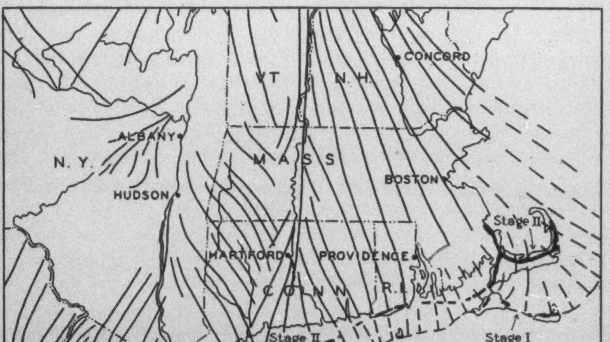

FIG. 1.— MAP OF SOUTHERN NEW ENGLAND.
Showing position of supposed moraines and two positions of the Wisconsin ice according to the classical view point.

one, for distinguishing materials deposited by early ice sheets from later ice sheets.

Glacial Theory in New England. The older group of geologists held that there was evidence of only one ice sheet in New England. The late J. B. Woodworth, however, held to the contrary and with some of his contemporaries showed that evidence is found on Cape Cod and the neighboring islands for successive ice invasions. In Gay Head Cliffs for instance Woodworth* shows that the soft Cretaceous and Tertiary beds are deformed by ice shove and that several sheets of till, gravel and marine clay attributable to the earlier ice sheets are also deformed. He arranges these beds into the following sequence:

Deposits on Cape Cod and the Islands.	Correlated Stages.
Wisconsin deposits (of Woodworth)	Wisconsin
Vineyard interval of erosion (no deposition)	Peorian (Retreatal stage) Iowan Sangamon (Interglacial stage)
Manhasset formation: Hempstead gravel Montauk Till Herod gravel	Illinoian
Jacob sand Gardiners clay: Transitional marine	Yarmouth (Interglacial stage)
Jameco formation: Moshup till Coarse gravel Boulder bed	Kansan
Mannetto clay—till and gravel Weyquosque glacial sand Dukes boulder bed	Nebraskan
Aquinnah Conglomerate (non glacial)	Pliocene

The beds older than the Gardiners clay are much iron-stained and weathered. Even the Manhasset series above the Gardiners is yellowish-brown. We cannot doubt that here as in Long Island† we deal with the record of successive ice invasions although there is much disagreement as to how many invasions there were.

The Last Ice. Woodworth followed his predecessors in believing that the last ice or late Wisconsin ice rested on the islands and covered all New England. Here new studies lead to a divergent viewpoint. The whole area of the Cape and of Marthas Vineyard except for small areas to be later explained is blanketed with a layer from 2 to 5 ft. thick of loose unconsolidated material which Woodworth believed to be the till of the last ice. However, this material contains wind-worn stones from top to bottom and must therefore have an origin under some set of conditions involving wind work and not burial under glacial ice. It appears that it is a frost-heaved layer due to the intense frost action characteristic of the near presence of glacial ice. The wind-worn stones are to be attributed to the same cause.

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*Woodworth, J. B. and Wigglesworth, E.; Geology of Cape Cod and vicinity, etc.: Harv. Coll. Musm. Compar. Zool. Mem. 72, 1934.

† Fuller, M. L.; The geology of Long Island, N. Y.: U. S. Geol. Survey Prof. Paper 82, 231 pp. 1914.

If these areas had no glacial ice in the very latest episode, where did the ice lie? One lobe lay outside the Cape, one in Cape Cod Bay and one further west. The western lobe is the most interesting. It followed down the great depression of the Connecticut Valley and near the present shore spread out to join the next western lobe of the Hudson Valley. These ice lobes combined to form a great sheet that covered Long Island Sound. The southern

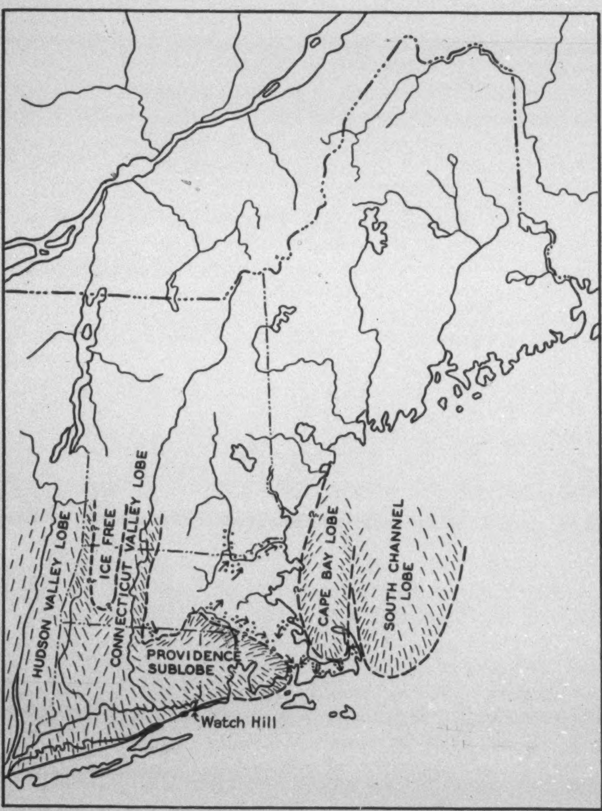
HUDSON VALLEY LOBE
ICE FREE
CONNECTICUT VALLEY LOBE
PROVIDENCE SUBLOBE
CAPE BAY LOBE
SOUTH CHANNEL LOBE
Watch Hill

Fig. 2.— Map of New England.
Showing position of the lobes and the limit of Wisconsin ice according to the new theory.

edge lay on the northern edge of the Island and on Fisher's Island. It extended along the south shore of Rhode Island from Harbor Hill to Narragansett Pier.

In this eastern portion there was a definite sub-lobe with an easterly direction of flow. Its border fluctuated rapidly but extended as far east as Mattapoisett. The northern border of this sub-lobe has not yet been well-traced but it extended northwest from Providence and thence westward.

Relation of Glacial History to Weathering. This episode of glacial history, however spectacular, involving the assumption of a block of ice not less than 1 000 ft. thick over this spot some 25 to 30 thousand years ago would, off-hand appear to have no immediate bearing on water supply. However, the deposits of this last ice have been subjected to weathering only a short time. They are relatively fresh and almost free of iron oxide.

The glacial deposits of the great highland of eastern Massachusetts and of the region near Boston are generally weathered and iron stained. Here is involved the question of iron in well-waters. I have plotted on the map all town supplies in Massachusetts derived from ground-water with an iron content of more than 0.19 p.p.m. I have also inserted the town supplies derived from surface waters having a similar content of iron. For Rhode Island I have used available data.

This system of using the available analyses and applying the results to the areas of whole towns gives only a rough approximation to the distribution of well waters that contain iron in sufficient quantity to be objectional for domestic use. Essex County, Massachusetts, is outstanding in the high iron content of its well waters and surface supplies. This condition is attributable to the high iron content of its bedrock and the relatively intense weathering to which the bedrock and its overlying glacial drift have been subjected. Similarly the highland west of Boston from the Rhode Island-Connecticut line north into New Hampshire is an area of compact and rusty till and of limonitic gravel. Well waters are strongly iron bearing. Such conditions are to be expected from the glacial theory set forth above. These areas have been continuously subject to weathering over a long period including at the least the Late Wisconsin and post-glacial time.

Within the area of the late ice, that is, in the Connecticut Valley and in Rhode Island the glacial drift is fresh and little weathered. Well waters with low iron content should be expected. In a broad way this conclusion is supported by plotting the available data but there are numerous exceptions. Wells with relatively high content of iron occur within the area of the new drift although the till above the bed rock is fresh and unweathered. Here the iron appears to be drawn from weathered bed rock below the fresh till. The largest area of this type lies within the Providence Sublobe in western Rhode Island. Here the massive Sterling granite gneiss although disintegrated and iron stained along joints appears to have resisted erosion by the late ice. Wells drilled into the rock in this area have a considerable iron content. The correlation between iron-bearing well water and the areas of older drift is thus not perfect, but the available data are also inadequate and not collected with this possible correlation in mind.

I have given you a brief account of the new theory of our glacial history and have attempted one correlation — a not wholly satisfactory one — with the practical problem of our ground-water supply. As this theory is perfected and our glacial deposits mapped in more detail, further correlations will be made. Some of them will, I feel sure, be of large practical importance.

OCCURRENCE OF IRON IN GROUND WATER AND EARLY EXPERIMENTS UPON REMOVAL.

BY H. W. CLARK.*

[*Read September 19, 1935.*]

Somewhat more than forty years ago the writer began to study the ground water supplies of Massachusetts, to investigate the amount of iron in some of these supplies, the cause of its presence in them and methods of treatment necessary for its removal. The results of this early work were published in an article in the Massachusetts State Board of Health's annual report for 1899, — that is, thirty-six years ago. The article was entitled "The Occurrence of Iron in Ground Waters and Experiments upon Methods of Removal." This was, I believe, some of the pioneer work in this country on this subject. In the beginning of that article I stated that of the forty or more public ground water supplies of the state that I studied not one was entirely free from iron at all times but only a few contained iron in a sufficient amount to be objectionable. I also stated that "The reason some of our potable ground waters contain considerable iron is quite well known but it may be stated again as follows. As rain water percolates through the ground it comes in contact in many places with organic matter to such an extent that in certain cases the dissolved oxygen with which it is saturated when reaching the ground is exhausted in oxidizing this organic matter. Carbonic acid takes its place and a considerable amount of organic matter is also taken into solution. Nearly all soils, sands and gravels contain iron in combination with silica and other mineral substances. Pure water has but little effect on this combined iron. Water as just described, however, containing organic matter in solution with free carbonic acid and no free oxygen often exerts a decided action on many soils and rocks whereby iron and other basic oxides are dissolved as carbonates, bicarbonates, etc. This occurs as the organic matter in solution in the water has a greater affinity for the oxygen of the iron oxides than does the iron itself, hence these oxides are changed from an insoluble to a soluble form. The ferrous bicarbonate upon aëration of the water or exposure to the air changes to ferric hydrate and precipitates. If the iron in the water, however, is caused by iron pyrites and probably certain other bodies, it will occur in the form of ferrous sulphate and the hydrate will precipitate much more slowly. This change and the taking into solution of any considerable amount of iron probably takes place where there is an entire absence of oxygen. It does not necessarily follow, however, that ground water containing considerable iron drawn or pumped from wells or filter galleries must show an entire absence of free or dissolved oxygen as some of the water may come through different soil strata than other portions or may have been of a purer character originally and hence free oxygen has not become exhausted during filtration through the ground."

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*Associate, Whitman & Howard, Engineers.

Now if water is pumped from the ground at a reasonable rate, water may be obtained for many years from most of our well fields almost free from iron, but if pumped too rapidly a troublesome amount of iron may be taken into solution due probably to several causes. In the first place it must come more rapidly through the ground and from greater distances. In doing this there is opportunity for more organic matter to be taken into solution and hence reduction of more iron oxides and the taking of this iron into solution. There is also in many cases an objectionable accumulation of fine iron-bearing particles around each well from which iron goes into solution, and of course other reasons might be cited.

As previously stated, of the forty or more ground waters examined at that time — forty years ago — only a few contained iron in sufficient amounts to be objectionable and cause a nuisance in the water supply. The objectionable waters were the then Provincetown, Reading, Marblehead, Watertown and Lowell supplies. I also found in the course of aëration, filtration and other experiments and so stated that iron was removed with more or less difficulty from water containing a considerable amount of organic matter but that the iron in the waters of Marblehead and Lowell and Watertown was easily and practically completely removed by aëration and filtration through sand even at very high rates. The two supplies at that time from which iron could be removed with difficulty were those of Provincetown and Reading. I tried various ways of removing the iron from the Provincetown water; by aëration and sand filtration, coke contact and sand filtration, iron contact and sand filtration and also as I stated in that article passing the water through a filter or tower of coarse coke for aëration and partial removal of iron followed by sand filtration, as was quite common abroad at that time and is now in this country. However, this method did not seem to work with the Provincetown water of that day, but iron contact and filtration was quite successful as this method caused the addition of enough iron to the water to cause precipitation. I also tried, and successfully, the removal of iron from the Provincetown water by oxidation with potassium permanganate and filtration. That famous chemist of years ago, Prof. W. R. Nichols, in his book upon Water Supply, published in 1883 first mentioned the use of potassium permanganate as an agent for the oxidation of organic matter present in water, but the use of this chemical as an oxidizing agent in the removal of iron from waters was at that time, I believe, a new thing. As I just stated it was successful and the amount of permanganate used was 75 lbs. per m.g. of water. Various investigations were made with the use of lime and other chemicals with Reading and other waters which were more or less successful and are all described in the Article of 36 years ago.

SOME PROBLEMS OF DEFERRIZATION AND DEMANGANIZATION.

BY ROBERT SPURR WESTON.*

[*Read September 9, 1935.*]

The methods for removing iron, manganese and carbon dioxide in ground water are various. Superficially one has only to replace carbon dioxide or other acid, which holds iron or manganese in solution, with oxygen, which changes the soluble salts of the troublesome metals to insoluble hydroxides, coagulate these hydroxides, and then settle or filter them out of the water. In principle this is easy, in practice sometimes exceedingly difficult.

The easiest cases for the removal of iron are hard waters moderately high in mineral matter and free from material amounts of organic matter and manganese. The hardest cases are those soft waters which contain little mineral matter, considerable organic matter and in which the ratio of manganese to iron is such that one interferes with the removal of the other. Difficulty also arises where the metals are in the form of sulphates.

The first class of water may be readily purified by simple aëration, followed in turn by a short period of storage and filtration through slow or rapid sand-filters.

Aëration may be accomplished by nozzles (low or high head), perforated pans, superimposed trays filled with coke, cascades, compressed air or mechanical agitators. Generally, spray nozzles or superimposed trays filled with coke are most effective, although mechanical agitators like those used in the activated sludge process of sewage treatment have not yet been tried out sufficiently to rate them properly. However, aëration, which is in effect the washing out of the free carbon dioxide with air, while easily accomplished, is not always all that is required for the removal of iron or manganese. The oxidation of the bicarbonates and sulphates and the flocculation of these troublesome elements must follow. Otherwise without flocculation the oxidized particles will be too fine to settle out in basins or be retained by filter sand.

The oxidation of the iron or manganese carbonate sets free carbon dioxide; the oxidation of iron or manganese sulphate, sulphuric acid, which in turn reacts with the alkali in the water setting free carbon dioxide in turn. For good results with certain waters this secondary carbon dioxide must be removed. This fact explains why contact aërators, which prolong aëration, are so effective. Dunbar of Hamburg, and others, have shown that the precipitated iron and manganese absorb oxygen during periods of rest and release it during periods of operation.

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* Of Weston & Sampson, Consulting Engineers, Boston, Massachusetts.

Large amounts of iron or manganese coagulate more readily than small. This is because of the larger mass precipitated in waters rich in these metals, increasing what chemists call mass action and surface absorption, in other words, the attraction of the smaller particles by the larger. To secure artificially the effect of this mass action in waters containing a small amount of iron or manganese, various devices like tricklers or contact-aërators, — filled with coke, stone or concrete blocks, special brick, crushed stone, excelsior or other material providing large contact surfaces, — are used. Water is sprayed or otherwise distributed over the accumulated hydroxides of iron or manganese deposited on the filling of the aërator. The effect is to collect the dispersed particles of hydroxides on the surface of the mass of hydroxide, deposited on the medium of the contact aërator during previous periods of service. After a time the accumulation, which has now become more granular, sloughs off and is then removed from the water by subsidence and filtration.

Engineers in Europe and, quite recently, Zappfe in this country have used Pyrolusite, a manganese ore containing 70 per cent. of dioxide as a contact (or catalytic) medium for removing manganese. Experiments lasting a relatively short time show this material to be more efficient than coke, stone or sand. The answer to the question whether or not it is permanently more efficient than stone or sand coated with manganic hydroxide and dioxide, previously removed from the water, is somewhat in doubt.

Manganese, while belonging to the same group of elements as iron and oxidizing more rapidly, is not so easily removed from water. Apparently it does not coagulate or form flocs so readily. For certain waters, especially those high in manganese, contact aërators operating on the upward-flow principle are most effective, this because the time of contact is prolonged. However, upward flow is not advisable unless the water is first aërated adequately or if accumulations of organic matter in the contact aërators would rob the water of its oxygen. Contact aërators of this type are apt to unload periodically. They are more easily cleaned than downward flow aërators.

An important application of this principle, long used abroad, was at Long Beach, New York, by Malcolm Pirnie.* Others are at Stuart and Punta Gorda, Florida. It has been used for a water high in manganese and organic matter supplying an estate on Nonnamesset Island and for the water supply of Georgetown, Mass.

Organic matter is a serious inhibitive factor in a water containing iron or manganese, probably because the particles or organic matter, as the ultramicroscope apparently shows, accumulate upon the highly dispersed particles of iron or manganese and prevent their gathering into aggregates large enough to be removed by subsidence and filtration. Consequently they pass through the filters.

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* Water Works Practice, p. 249.

A good example of this was at Amesbury, Mass. Here water was taken from shallow wells along the Pow-wow River, aërated by the spray nozzles and then passed through a contact aërator or trickler containing 6 ft. of coke, to subsiding basins and high-lift pumps. This well water contained an average of 7 p.p.m. of iron and 0.4 p.p.m. of manganese which for several years were reduced to about 0.05 and 0.03 p.p.m. respectively.

In the three months prior to August, 1934, the iron in the filtered water rose from 0.04 to 1.40 p.p.m. Something was wrong. When the river was high, the wells were surrounded with surface water and the color of the well water rose. Chemical analysis showed higher organic matter in the well water. It appeared that the colored surface water was leaking into the well system either through leaks in the piping or by passage from the surface to the water-bearing stratum and that organic matter in the surface water was preventing the coagulation of the iron and manganese. Complaints began, and prompt action had to be taken. Accordingly, chlorine in the form of H.T.H. was added to the well water to oxidize the organic matter in the well water before it could interfere with the coagulation of the metals. It worked. By September the iron in the delivered water had fallen to 0.04 p.p.m.

This year the same trouble has been repeated in kind although not in degree, and the same remedy has been used to effect the removal of the iron. Meanwhile the well system is being examined so that surface water may be excluded from the true ground water in the future.

Not only chlorine but potassium permanganate may be used to oxidize interferring organic matter, but the best practice would seem to be to employ aëration and contact wherever possible, even going to the extent of returning the sediment from subsiding basins to the entering raw water, as precipitated chalk is returned from the basins of softening plants and as sludge is returned in the activated-sludge process for sewage.

Many times, engineers overcome difficulties in the deferrization or demanganization processes by adding lime, soda or coagulating chemicals. When the dose of lime is large enough to raise the pH value to 8.4, practically all of the iron and manganese will be removed without contact treatment and even with inefficient aëration. On the other hand, it hardens the water and involves the cost of chemicals, so it is not often employed for soft waters. As part of the softening process, it is of course effective, and where waters contain large amounts if iron or manganese in the form of sulphates the added alkali neutralizes the acid released by oxidation.

The addition of sulphate of alumina will help coagulate iron and manganese, oxidized but highly dispersed. Here again one adds a chemical of price and increases somewhat the burden on the filters. It, therefore, seems better when practicable to depend upon aëration and contact.

At Lowell, Mass., Superior, Wis., and Merrimack, N. H., it was found that partial aëration prevented the interference of the organic matter with the coagulation of the iron and manganese. Apparently the residual carbon dioxide prevented a combination between the organic matter and the dispersed hydroxides.

Carl Zapffe[*] in a scholarly historical paper mentions five periods in the development of the art of demanganization, namely, Bacteriological, 1836–1906, Inorganic Chemistry, 1906–1934, Physico-Chemistry, 1914–1922, Catalysis, 1922–1930, and Modern, since 1930. The latter period includes his experimental work at Brainerd, Minn., and the building of the Municipal Plant there. He cites the part which the bacteria play in the formation of deposits in mains, also in filters and aërators, and shows that while manganese could be removed by contact and catalysis, the lessons as to conditions needed to be learned are in the bio-chemical book, most easily read in the geological depositions.[†] He showed, as Weston[‡] had stated, that the deposited, slowly forming, manganese dioxide is the active catalytic agent which removes manganous salts from solution in water after removal of carbon dioxide.

In the Brainerd plant the raw water is forced upward through a considerable thickness of Pyrolusite,—evidently to provide an excess of dioxide in contact with the water, — and is then sprayed on to a contact aërator of coke. Here the manganous hydroxide is oxidized and coagulated to form stable manganic compounds, the water having a pH value of 7.2 to 7.3. In this plant the efficiency of pretreatment is shown by the removal of 80 per cent. of the iron and manganese. The filters remove the remainder.

This practice rests upon the firm foundation of the experiments of Tillmans, Hirsch and Grohman,[§] who found surface area to be the dominant requirement; that the oxygen requirement was easily met and that one can substitute, by treatment with alkali, a higher pH value for sufficient oxygen, or reach the same end by keeping the carbon dioxide low. It was also found that in the Brainerd water[**] manganese did not interfere with iron removal, but that iron oxide by occluding the contact surfaces interfered with the removal of manganese.

The efficiency of contact for manganese removal is illustrated by the experience at Leipzig[††] where 20 per cent. of used sand comprises the make-up of the filter layer and care is taken not to scrape the sand too deeply when cleaning filters, lest the essential manganic compounds be removed with the scraped sand.

In the above connection one realizes that the formation of Pyrolusite in nature, so efficient at Brainerd and elsewhere, is but the final stage of which the accumulation of manganic compounds in contact aërators is the analagous beginning. Consequently, one must believe that a sufficient accumulation of freshly precipitated manganic compounds will do the work of the manganese ore provided a large enough surface is provided. Furthermore, any bed of Pyrolusite may in time become coated with hydroxides deposited from the water when its effect will be that of the accumulation but not that of the ore itself, unless, perhaps adequate cleaning be practiced.

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[*] The History of Manganese in Water Supplies and Methods for its Removal. — J. A. W. W. Assn. **25**, 655.

[†] Deposition of Manganese.— Econ. Geol. **26**, 8, 799–832 (1931).

[‡] Manganese in Water, Its Occurrence and Removal.— J. A. W. W. Assn. **24**, 1272 (1932).

[§] The Physical Chemistry of Demanganization of Drinking Water; Gas — und Wasserfach. I — **70**: 25, 1927; II — **71**:21, 481–487, 1928; III — **71**:22, 51–519, 1928.

[**] Containing 1.2 p.p.m. of iron and 0.8 p.p.m. of manganese.

[††] Versuche zur Entmanganung des Leipziger Trinkwassers. Kaatz and Richter, Gas u. Wasserfach **77**, 291–294 (1934).

At Lincoln, Nebraska, Erickson* reported the results of experiments by Baylis and described the plant designed by Black and Veatch. The experiments showed that contact filters containing Pyrolusite were effective in the beginning but, due to coatings on the mineral, lost their efficiency in less than 60 days. While the Pyrolusite could have its efficiency restored by acid treatment and cleaning, it was not superior to coke or gravel as a contact filter medium. The treatment finally adopted was aëration with chlorination, followed by passage through upward-flow contact beds, a basin storing 2 hours flow, and rapid filters. Treatment was so effective that the filters could be operated at double the usual rates.

Removal by Zeolite. Manganzeolite, which is sodium zeolite treated with manganous chloride, has been used successfully for removing manganese from water. This material is regenerated by treating it with potassium permanganate. Applebaum† states that the zeolite functions as an active carrier and catalytic reagent. For large supplies the cost of permanganate ($1.50 to $2.50 per million gallons) would be a factor.

It is also possible to combine zeolite softening with deferrization and demanganization. Sometimes, however, iron or manganese in the water interferes with the performance of the zeolite.

At South Orange, N. J., where zeolite softeners have been in use for several years, it was found necessary to aërate the water so that the small amount of iron might be changed from the soluble to the insoluble condition and removed from the surfaces of the zeolite particles by washing rather than enter the pores of the zeolite in solution, and there accumulate and lower its efficiency.

At the plant of the Ohio Valley Water Co., below Pittsburgh, where Borromite, a natural zeolite, was used in pressure filters, manganese was removed without difficulty and without deterioration of the softening medium. Apparently the precipitated manganese hydroxide was easily washed from the zeolite, when the latter was regenerated.

Closed Systems. Closed systems, or systems using pressure filters, have been in use for over 30 years. In these the filter material may be sand, Pyrolusite or one of the various proprietary materials.

Because one part of oxygen is sufficient to oxidize seven parts of iron, elaborate aërators and contact devices would seem to be unnecessary, and indeed it is true that for some waters closed systems suffice. Generally, however, additional aëration, neutralization with alkali, or special catalytic filtering media, one or all, are demanded. These stipulations generally outweigh the avoidance of double pumping, which is unnecessary with pressure filters and which with lower construction cost in some cases seem to be their chief advantages.

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* The new Iron and Manganese Removal Plant for Lincoln, Nebraska, Jour. A.W.W.A. **27** (1935) 337.

† S. B. Applebaum, J. Ind. & Eng. Chem. **8**, 160 (1916).

In a forthcoming paper in the *Journal of the American Water Works Association*, Dr. Frank E. Hale of the New York Department of Water Supply describes his successful method of removing ferrous carbonate from water by treatment with lime, in a closed system, and in the complete absence of oxygen. Naturally the dose of lime had to be sufficient as in the softening process to precipitate all of the iron as hydrate, and the treated water has a high pH value. Nevertheless, the method is ingenious and in the case described solved a problem where other methods could not be conveniently applied.

Filters. Properly treated waters may be filtered through either slow or rapid filters; where chemicals are used, rapid filters are generally indicated. The choice between slow and rapid filters often depends upon size of plant, convenience for operation or location rather than upon qualitative efficiency. However, the slow filter is more dependable, especially for waters containing manganese, because greater opportunity is given for catalysis.

The difference in cost between the two types is small. This is because rates of 8 m.g.d. per acre or more may be employed for slow filters. For example, — a cost of $175 000 per acre for slow filters would be equivalent to from $17 500 to $22 000 per m.g. or within range of the cost of rapid filters designed for a rate of 2 gal. per sq. ft. per minute (125 m.g.d. per acre). At higher rates, which are sometimes practicable, the rapid filter would naturally be less expensive.

DATA ON MASSACHUSETTS PLANTS AND OTHERS.

	Middleboro, Mass.	Amesbury, Mass.	Georgetown, Mass.*	Brookline, Mass.	Marblehead, Mass.
Date built	1913	1927	1935	1916	1909
Capacity — m g.d.	1.0	1.5	0.14	10	3
Spray aerators	1	2	1	6	1
Number of nozzles	37	90	9	366	None
Type	Drilled caps	Drilled caps	Drilled caps	Drilled caps	Perf'r't'd pan
Contact aerators	1	2	2	6	None
Area — sq. ft.	628	1440	130	4260	....
Depth — ft. (total)	10.0	3.0	4.0	10	....
Type	One bed	One bed	†	One bed	....
Subsiding basin	1	2	None	1	1
Capacity — gal.	40 000	112 000	....	510 000	125 000
Detention period — hrs.	1.0	1.8	....	1.2	1.0
Filters	2	2	2	6	3
Area, acres (total)	0.10	0.2	0.018	1.0	0.3
Rate of filtration — m.g.d. per acre	10.0	7.5	8.0	10	10
Filtered water basin:					
Capacity — gal.	42 000	250 000	78 000	2 390 000	140 000
Iron content of raw water — p.p.m.	3.4	6.9	0.7	1.7	2.0
Manganese content of raw water — p.p.m.	0.7	0.4	0.04	0.03	0.25
Iron content of effluent — p.p.m.	0.27	0.05	....	0.08	0.13

* Partially completed.
† Submerged upward flow.

DATA ON MASSACHUSETTS PLANTS AND OTHERS (*Continued*).

	Lowell, Mass.	Reading, Mass.	Cohasset, Mass.	Forbes Est. Naushon Island, Mass.	Memphis, Tenn.
Date built	1915	Being built	1913	1931	1924
Capacity — m.g.d.	10.0	1.5	1.2	0.017	18.0
Spray aerators	6	2	1	1	....
Number of nozzles	384	80	37	None	None
Type	Drilled caps	Drilled caps	Drilled caps	Cascade	Perf'r't'd pan
Contact aerators	6	2	1	1	40
Area — sq. ft.	654	1280	628	18	560
Depth — ft. (total)	10	4.0	10	5	3.3
Type	One bed	One bed	One bed	†	4 trays
Subsiding basins	2	2	1	None	1
Capacity — gal.	500 000	67 000	51 000	....	240 000
Detention period — hrs.	1.2	1.0	1.0	....	0.3
Filters	6	2	3	1	8
Area — acres (total)	1.0	0.19	0.009	0.0016	0.15
Rate of filtration — m.g.d. per acre	10	8.0	125	10.0	121
Filtered water basin:					
Capacity — gal.	1 000 000	155 000	34 000	3 500	9 000 000
Iron content of raw water — p.p.m.	2.2	0.5	0.8	12.0	0.6
Manganese content of raw water — p.p.m.	2.1	0.06	....	0.5	0.06
Iron content of effluent — p.p.m.	0.27	....	0.16	0.01	0.03

† Submerged upward flow.

DATA ON MASSACHUSETTS PLANTS AND OTHERS (*Continued*).

	Wellsburg, W. Va.	Priv. Plant, Griffin, Ga.	Am. Glue Co., Peabody, Mass.	Kokomo, Ind.	Warrenton, N. C.
Date built	1931	1923	1923	1930	1930
Capacity — m.g.d.	....	1.0	2.1	3.0	.18
Spray aerators	2	2	1	None	None
Number of nozzles	None	66	19	....	....
Type	Perf'r't'd pipe	Drilled caps	Sacramento	....	....
Contact aerators	2	2	1	4	1
Area — sq. ft.	....	594	707	40	....
Depth — ft. (total)	....	6	1	....	7.0
Type	4 trays	One bed	One bed	5 trays	2 trays
Subsiding basins	1	2	1	1	2
Capacity — gal.	....	46 000	66 000	....	25 000
Detention period — hrs.	....	1.1	0.8	....	3.3
Filters	3*	4	4	6	1*
Area — acres	....	0.01	0.018	0.025	0.0011
Rate of filtration — m.g.d. per acre	160	100	115	185	157
Chemical treatment	None	None	None	None	Yes
Chemical	....	....	....	....	Lime
Dose — p.p.m.	....	....	....	....	17
Point of application	....	....	....	....	Mixing drain
Mixing basins	None	None	None	None	1
Capacity — gal.	....	....	....	....	2700
Detention period — min.	....	....	....	....	21
Filtered water basin:					
Capacity — gal.	....	....	235 000	120 000	5200
Iron content of raw water — p.p.m.	....	0.2 to 2.0	1.5	3.0	0.75
Manganese content of raw water — p.p.m.	1.0	....	....	....	0.15
Iron content of effluent — p.p.m.	....	0.2	0.2	0	0.26

* Pressure.

Rapid filters involve frequent attendance for washing, while slow filters will run without attention for comparatively long periods. This is to the advantage of slow filters in towns of moderate size, where a daily inspection is all that can be given, especially to plants located well out of town, excepting when a filter bed needs scraping or raking. Then the labor force may be transferred to the deferrization plant and the job done. Rapid filters, when operating economically, must be washed whenever dirty, usually oftener than once a day, and at irregular intervals.

Plants in Practice. In the accompanying table are collected various engineering data regarding deferrization and demanganization plants. The list is by no means complete, excepting possibly for New England, but it is believed that it illustrates the various types of plants in operation.

PROCEEDINGS.

FEBRUARY MEETING.

HOTEL STATLER, BOSTON, MASS.

Thursday, February 20, 1936.

President Roger W. Esty in the chair.

Secretary GIFFORD announced the election by the Executive Committee of the following:

Members: Justus W. Patterson, Manager New England Division, Northeastern Water & Electric Service Corporation, Millbury, Mass.; Leonard Dominque, Foreman of Distribution and Maintenance, Water and Sewerage Commission, Marlboro, Mass.; Alexander J. Minkus, Laboratory Assistant, Slow Sand-Filtration Plant, Hartford, Conn.

Associate: Turbine Equipment Co. of New England, Boston, Mass.

ARTHUR D. WESTON presented the following resolution.

WHEREAS there has been introduced into Congress certain legislation relative to the pollution of streams, namely, Senate Bill 3958 and Senate Bill 3959, which, if enacted, may interfere with state rights; and

WHEREAS Federal interference in the matter of stream pollution may adversely affect water supply developments;

BE IT RESOLVED that the NEW ENGLAND WATER WORKS ASSOCIATION, at its meeting held February 20, 1936, go on record as being opposed to any legislation placing the regulation of stream pollution under Federal authority, and that the NEW ENGLAND WATER WORKS ASSOCIATION advise each New England senator and representative in the United States Congress to this effect, and also to the effect that the NEW ENGLAND WATER WORKS ASSOCIATION desires that Federal activities in matters of stream pollution be limited entirely to fact finding and coöperation with state authorities when officially requested.

After discussion, this resolution was adopted.

James J. Fitzgerald, Chairman of the Springfield Committee on Pensions, gave a talk on "Pending Pension Legislation in Massachusetts." Brenton W. Vaughan, Henry V. Macksey, and Arthur C. King took part in the discussion.

A paper, "B. Coli — What Are They and What Do They Signify," was read by Gail P. Edwards, Laboratory Coördinator, Massachusetts Department of Public Health, Boston, Mass. The paper was discussed by Linn H. Enslow.

A paper, "Water Department Regulation of Water Pipes Within Buildings," was read by Stephen H. Taylor, Superintendent, New Bedford Water Works, New Bedford, Mass. David Heffernan, Warren J. Scott, William F. Sullivan, George F. Merrill, Percy A. Shaw, Francis H. Kingsbury, Arthur V. Harrington, Henry T. Gidley, Arthur L. Shaw, and Richard H. Ellis took part in the discussion.

The topics, "Why Water Superintendents Lie Awake Nights," and "Good Ideas That Didn't Work," were discussed by the following: Harold L. Brigham, Superintendent, Marlborough Water and Sewage Commission, Marlborough, Mass.; Walter B. Bushway, Superintendent, Brookline Water Department, Brookline, Mass.; Horace J. Cook, Superintendent, Auburn Water District, Auburn, Maine.; Patrick Gear, Superintendent, Holyoke Water Department, Holyoke, Mass.; George E. Hawkins, Superintendent, Brattleboro Water Department, Brattleboro, Vt.; Samuel E. Killam, Superintendent, Distribution Section, Water Division, Metropolitan District Commission, Boston, Mass.; George F. Merrill, Superintendent, Water Department, Ware, Mass.

[*Adjourned.*]

MARCH MEETING.

HOTEL STATLER, BOSTON, MASS.

Thursday, March 19, 1936.

President Roger W. Esty in the Chair.

Secretary GIFFORD. The Executive Committee at this morning's session elected the following members: Howard Huntington Potter, Assistant Engineer Public Utilities Commission of Maine, Augusta, Me.; Allen Jeffers Burdoin, Engineer with Howard M. Turner and Samuel L. Ellsworth, Boston, Mass.; Donald Percy Johnston, Assistant Superintendent Bangor Water Department, Bangor, Me.; Charles Edward Greene, Mechanical and Electrical Engineer with Metcalf & Eddy, Boston, Mass.

THE PRESIDENT. According to the constitution of the Association it becomes necessary for the members to appoint a Nominating Committee at this meeting.

What is your pleasure in this matter?

[It is duly moved and seconded that the President be empowered to appoint a nominating committee. The question being taken, the motion is unanimously agreed to.]

A talk on "Radio in World Telephony" was given by J. W. Kidder, Toll Plant Extension Engineer, New England Telephone & Telegraph Company of Boston, supplemented by a short talking movie entitled, "The Sea-Going Telephone," which was followed by a radio telephone conversation between Mr. Charles Duffy of the New England Telephone & Telegraph Company and the Captain of the trawler *Hecla*. This paper was discussed by President Esty and Henry T. Gidley.

A paper, "Changing a Town from Flat Rates to Meter Rates," was read by Dwight L. Agnew, Manager of the Hingham and Cohasset Water Company, Hingham, Mass. Messrs. Stephen H. Taylor, Henry T. Gidley, Frank J. Gifford, and Roger W. Esty participated in the discussion.

A paper, "Effect of Air Conditioning on Water Consumption," was read by Harry C. Mayo, Vice-President and General Manager of Lawton Engineering Corporation of Boston. Messrs. Roger W. Esty, E. C. Sanderson, and David A. Heffernan participated in the discussion.

[*Adjourned.*]

SPRING MEETING.

HARTFORD, CONNECTICUT.

Tuesday, April 28, 1936.

After an inspection trip of the Hartford Water Works, luncheon was served at the Farmington Country Club, Farmington, Conn.

President Roger W. Esty in the Chair.

The Association was welcomed by Hon. Charles A. Goodwin, Chairman, Metropolitan District Commission of Hartford.

The President announced the death of John C. Chase, Derry, N. H., the oldest member of the Association.

A paper, "Preliminary Investigations and Design of Bills Brook Dam," was read by William Dorenbaum, Designing Engineer, Water Bureau, Metropolitan District, Hartford, Conn. A motion picture, "Construction Methods at Bills Brook Dam," was shown. Caleb Mills Saville, Percy A. Shaw, Howard M. King, Henry T. Gidley, F. F. Longley, and Samuel M. Ellsworth took part in the discussion.

A paper, "Distribution System Problems," was read by Edward E. Minor, Manager and Chief Engineer, New Haven Water Company. The paper was illustrated by slides.

A Round Table Discussion of Recent Flood Problems was participated in by Arthur D. Weston, Warren J. Scott, President Esty, George F. Merrill, and Caleb Mills Saville.

SPRING MEETING.

EAGLE HOTEL, CONCORD, N. H.

Thursday, May 21, 1936.

President Roger W. Esty in the Chair.

The Association was welcomed by Harry H. Dudley, President of the Board of Water commissioners, Concord, N. H.

A paper "Description of the Concord Water Supply," was read by Percy R. Sanders, superintendent, Concord Water Works, Concord, N. H. Harry U. Fuller, Robert Spurr Weston, Percy A. Shaw, Milton Thorne, Theodore L. Cate, Donald C. Calderwood, Francis H. Kingsbury, Hervey A. Hanscom, Henry T. Gidley, J. H. Reed, Leonard W. Trager, and Frank J. Gifford took part in the discussion.

A paper "Experience with Public Water Supplies during the Recent Flood," was read by Leonard W. Trager, Associate Sanitary Engineer, Division of Chemistry and Sanitation, Concord, N. H. Francis H. Kingsbury, Frank J. Gifford, George F. Merrill, E. Sherman Chase, and Robert Spurr Weston participated in the discussion.

A paper, "Improving the Manchester, N. H., Water Supply by Drainage Diversion," was read by Percy A. Shaw, Engineer and Superintendent, Manchester Water Works, Manchester, N. H. Francis H. Kingsbury, Henry T. Gidley, Harry U. Fuller, R. S. Holmgren, E. Sherman Chase, Robert Spurr Weston, and George F. Merrill took part in the discussion.

A rising vote of thanks was extended to the Board of Water Commissioners of Concord, the Superintendent, and the members of the program committee of the meeting.

[Adjourned.]

XANTHUS HENRY GOODNOUGH.

Xanthus Henry Goodnough, son of Xanthus and Kate (Harley) Goodnough, was born in Brookline, Mass., on October 23, 1860, and died at Waterford, Me., on August 10, 1935. He prepared for college at the Brookline High School and was graduated from Harvard College in 1882. During his college course, not only was his scholastic record good but he also was prominent in athletics, being for four years stroke of his class crew which is reputed to have won all its races.

After graduating Mr. Goodnough was employed for a short time by the Boston Main Drainage Commission, and then in general railroad work in the West. Returning to Massachusetts in 1885 he worked with the Massachusetts Drainage Commission on investigations concerning the North Metropolitan Sewerage System. In 1886 he entered the employ of the Massachusetts State Board of Health as an assistant to the late Frederic P. Stearns, Chief Engineer, and upon Mr. Stearns' resignation in 1895 Mr. Goodnough succeeded him. This position he held until 1914 when upon the reorganization of the Board he became Chief Engineer and Director of the Division of Sanitary Engineering in the Massachusetts Department of Public Health and continued in this position until, owing to age limitation, he was retired in October, 1930. Upon his retirement, Mr. Goodnough invited Bayard F. Snow to join him in forming an engineering organization, which under the name of X. Henry Goodnough, Inc., has continued engineering practice, principally in the fields of water supply and sewerage. In this way Mr. Goodnough kept in touch with engineering and sanitary matters up to his final illness.

During the thirty-five years that he was Chief Engineer of the Board of Health and Department of Public Health Mr. Goodnough guided that Board and Department ably and efficiently in matters of water supply, sewerage, sewage disposal, improvement of rivers, etc., and was engineer of some of the largest and most important public health investigations and projects ever undertaken by the state. His work of this character began as an assistant to Mr. Stearns during the investigations and the working out of the plan for the establishment of the Metropolitan Water Supply System for Boston and surrounding cities and towns, and thirty years later, during 1919–22, he was Chief Engineer of a Joint Board which investigated the enlargement of this metropolitan supply by extending the system to the Ware and Swift rivers. His recommendations relative to this extension were contained in an elaborate and able report. His plan for enlarging the system was at first rejected, and a second commission proposed an entirely different plan. Finally, after extended legislative hearings and much controversy between the proponents of these two plans, Mr. Goodnough's plan was adopted. Throughout these hearings he displayed the able and adroit generalship always evident in his work. Upon the formation of the Metropolitan District Water Supply Commission to carry out this project he was appointed one of its consulting engineers and after his retirement in October, 1930, through the corporation of X. Henry Goodnough, Inc., of which he was a member, he continued to render services as such consulting engineer even to the time of his last illness.

Among many other investigations made by Mr. Goodnough, the following may be mentioned as typical of his work: In 1895 he had charge of engineering work for improving the Concord and Sudbury rivers and the rebuilding of bridges over these streams; in 1895–97 he had charge of investigations for the improvement of the Neponset River and the Fowl Meadows and during 1911–15 he was engineer for carrying out this work; in 1896 he had general charge of an investigation for a sewerage system for Salem and Peabody; in 1899–1900 he had charge of further investigations for a main sewer for the South Metropolitan District and a new outlet into Boston Harbor; in 1906–07 he had charge of studies for the improvement of the Mystic River and Alewife Brook and designs for the improvement of the water supply of the City of Lynn; in 1914 he made plans for the extension of the Metropolitan Sewerage System in the Charles River Valley; in 1916 he, jointly with the City Engineer of Lynn, planned a new sewerage system for that city; from 1923–27 he was in charge of various special investigations for water supplies for Lawrence, Lowell and Methuen, and during the same years had charge of planning a general sewerage system for Salem, Peabody, Beverly and Danvers.

Apart from his work for the Commonwealth of Massachusetts he was from time to time consultant for various municipalities and water and sewerage districts concerning water supply, sewerage and other sanitary engineering matters; among these, during 1907–08 for the City of Boston in regard to municipal waste disposal, during 1914 for the City of Providence in regard to water supply, and for the Metropolitan Sewerage Commission of New York, and during 1926 for the County of Los Angeles, Calif., concerning sewerage.

On account of his intimate knowledge of all water supplies, sewerage systems and rivers of the State and his direction of engineering studies for the solution of a great variety of sanitary problems, he was preëminently known as an expert in public health engineering. His mastery of methods within his field made him a commanding figure in legislative committees before whom he was often called for consultation and advice, and he was alert and skillful in presenting his point of view before these committees. He was an efficient executive and understood the delicate art of human engineering, how to deal with men and how to get things done. He was a lover of mountains, forests, streams, and outdoor life, an ardent fisherman and a good companion.

Mr. Goodnough was the author of papers on various engineering subjects, including rainfall, stream flow, freshets, yield of watersheds, ground water supplies, drainage, disposal of sewage and municipal refuse, and in 1921 was the recipient of the Dexter Brackett Memorial Medal of the NEW ENGLAND WATER WORKS ASSOCIATION for his paper on Rainfall in New England.

Mr. Goodnough was a member of the following societies: American Society of Civil Engineers, American Water Works Association (Honorary Member), NEW ENGLAND WATER WORKS ASSOCIATION (Honorary Member), Boston Society of Civil Engineers, Harvard Engineering Society (Past President), Society of the American Military Engineers, American Meteorological Society and American Geographic Society.

On October 5, 1892, he was married to Maria T. Dyer, who died on January 13, 1925.

Mr. Goodnough was elected a member of the NEW ENGLAND WATER WORKS ASSOCIATION on January 14, 1891, and was made an honorary member on June 21, 1927.

ARTHUR D. WESTON,
HARRY W. CLARK,
BAYARD F. SNOW.

FAYETTE F. FORBES

Fayette F. Forbes, Member for almost fifty-one years, Past President and Honorary Member of the New England Water Works Association, died at his home in Brookline, Mass., on November 20, 1935. Mr. Forbes was born in Buckland, Mass., on May 9, 1851; he attended Williston Academy and the Massachusetts Institute of Technology, expecting to follow the occupation of Civil Engineer; after experience in engineering parties for several years, he held a responsible position in the first surveys for and in the initial construction of the Brookline Water Works and was appointed Superintendent of the system when it was put in operation in 1875, holding this position for the unusually long period of sixty years. A more accurate title of his actual position would be Engineer and Superintendent inasmuch as in addition to filling the latter position in a most efficient manner, he also designed and supervised practically all of the many additions and extensions to the system, such as a covered reservoir, well fields and filtration works, required from time to time by an increase in the population of Brookline from 7 000 in 1875 to 53 000 in 1935.

Mr. Forbes was a pioneer in the use of the microscope to distinguish and classify the microörganisms in drinking water in order to detect the particular forms of algæ responsible for objectionable taste and odors in the water. He began this biological work in 1885 and for years made microscopic examinations of samples of water taken from the Brookline Reservoir; he contributed three valuable technical papers on this subject to the Journal of the New England Water Works Association, the first in 1890, when such literature was in its infancy.

Mr. Forbes was also a pioneer in the restriction of waste of water, fully realizing that such action was mandatory in the case of the limited ground water supply of Brookline; beginning his campaign to reduce consumption in 1881, he persisted in his efforts until all service pipes in the system were metered early in 1905.

In addition to his high standing in the water works field, he was a botanist of note, going far afield in vacation time to collect specimens of the flora of New England and Canada. He maintained an herbarium at his home from which a large number of specimens have been presented to and gratefully received by Harvard University.

In the midst of a busy life, Mr. Forbes found pleasure and recreation in music, in which he became sufficiently proficient to be accepted as a violinist by the Boston Orchestra Club, an amateur organization of the highest standing.

Mr. Forbes was President of the NEW ENGLAND WATER WORKS ASSOCIATION in 1899 and was made an Honorary Member in 1927. He contributed in all twelve valuable papers to the JOURNAL of the Association.

Mr. Forbes was an able, forceful and unusual man of the highest type; of strong convictions; conservative, yet forward looking and farseeing; intellectual and kindly. His devotion to duty was outstanding as is strikingly evidenced by the following remark made by him several years ago to one of the writers of this memoir: "Remember the water in the Brookline mains is part of my life's blood."

Mr. Forbes was married on March 15, 1876, to Rose L. Thayer, deceased, and is survived by his widow Mrs. Nina M. Forbes.

Besides belonging to the NEW ENGLAND WATER WORKS ASSOCIATION, Mr. Forbes was an Honorary Member of the Netherlands Botanical Society and a member of the New England Botanical Club, Beth Horon Lodge A. F. and A. M., Appalachian Mountain Club, Brookline Firemens Relief Association, and Boston Society of Civil Engineers.

FRANK A. MCINNES, *Chairman*,
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INDEX OF ADVERTISERS.

Page
Atlas Mineral Products Co. xxvi

Barbour, Frank A. ii
Barrows, H. K. ii
Bingham & Taylor iv
Builders Iron Foundry ix

Caldwell, Geo. A., Co. xv
Cement Lined Pipe Co. xxvii
Columbian Iron Works xxxiii

Darling Valve & Mfg. Co. xi
Donaldson Iron Co. xxvi

Eddy Valve Co. xvii
Edson Corp., The x
Ellsworth, Samuel M. ii

Fairbanks-Morse & Co. xxi
Fay, Spofford & Thorndike ii
Ferullo, G., Inc. iii
Field, Walter W. & Son, Inc. iii
Ford Meter Box Co. xix
Fuller & Everett ii

Goodnough, X. Henry, Inc. ii
Golden-Anderson Valve Specialty Co. xxiv

Hayes Pump and Machinery Co. xix
Hays Mfg. Co. xx
Hersey Mfg. Co. v
Hotel Pennsylvania . . . . Following front cover
Hughes, Edward F. iii
Hydraulic Development Co. xii

Jenkins Bros. xxxv
Johns-Manville xxxvi

Kennedy Valve Mfg. Co. xvi
Kitson Co. xxxvi

Layne-Bowler New England Co. iii
Leadite Co. . . . . Back cover
Lock Joint Pipe Co. . . . . Facing front cover
Ludlow Valve Mfg. Co. xxvii

Metcalf & Eddy ii

National-Boston Lead Co. xviii
National Meter Co. xiv
National Water Main Cleaning Co. viii
Neptune Meter Co. vi
New England Water Works Association . . . . viii xix, xxvi

Pirnie, Malcolm ii
Pierce-Perry Co. xxvii
Pitometer Company ii
Pittsburgh Equitable Meter Co. vii

Red Hed Mfg. Co. xxxiv
Rensselaer Valve Co. xxv
Ross, Anthony & Son, Inc. iii
Ross Valve Mfg. Co. viii

Smith, The A. P., Mfg. Co. xix

Thorpe, Lewis D. ii
Turbine Equipment Co. xxii

Union Water Meter Co. xxvii
U. S. Pipe and Foundry Co. . . . . Facing back cover

Wailes Dove-Hermiston Corp. xxv
Wallace & Tiernan xxiii
Warren Foundry and Pipe Corp. x
Weston & Sampson iii
Whitman & Howard iii
Wood, R. D., & Co. xxviii
Worthington-Gamon Meter Co. xiii

(Classified index on page xxix)

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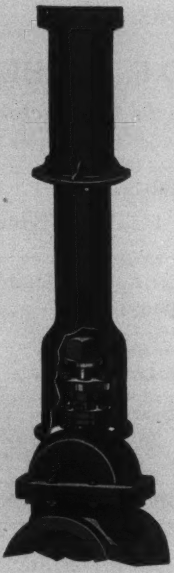

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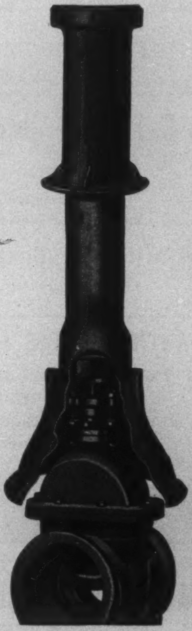

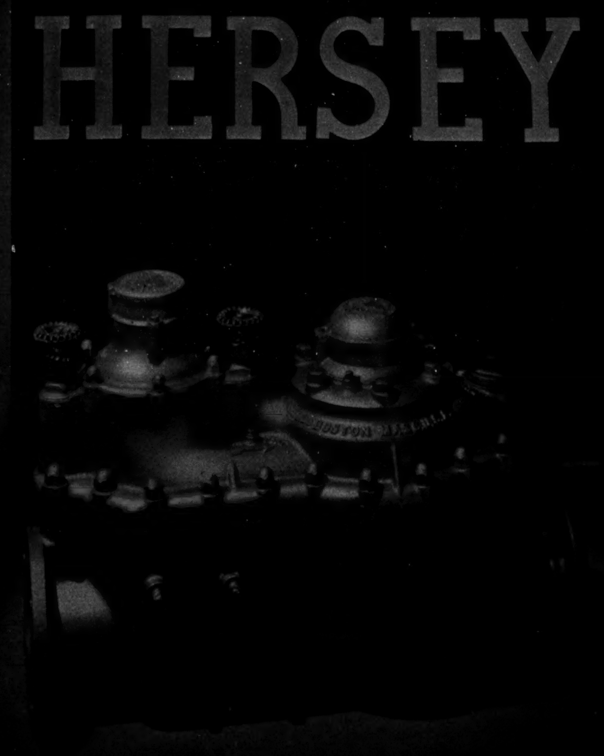

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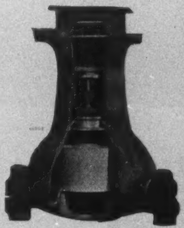

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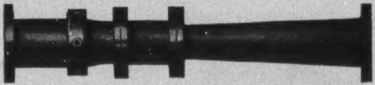

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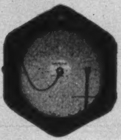

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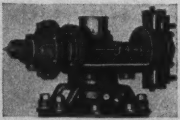

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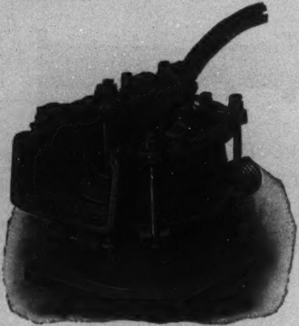

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New York: 142 Ashland Place, Brooklyn

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ALSO
Warren Pipe Co. of Mass., Inc.

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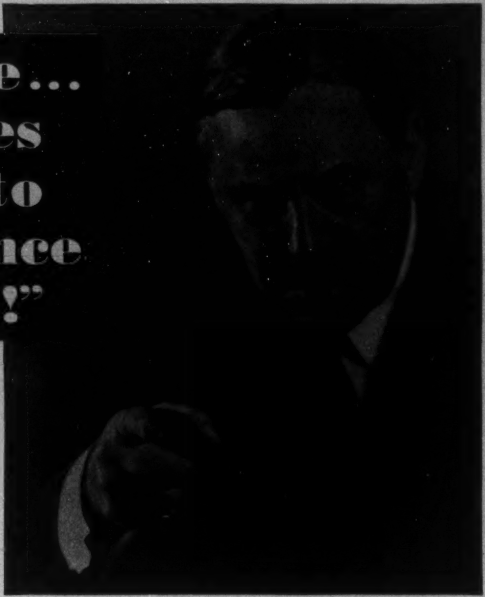
Manufacturers of
CAST IRON PIPE
Flanged Pipe *Flexible Joint Pipe*
Bell and Spigot Pipe
Special Castings *Short Body B. & S. Specials*
Warren Ⓦ *Spun Centrifugally Cast Iron Pipe*
WORKS: PHILLIPSBURG, N. J. and EVERETT, MASS.
Large Stock Enables Us to Make Prompt Shipments

"Sure... it takes a lot to convince me!"



Darling Fire Hydrants deliver an abundance of water and offer five other important advantages.

THE man who is hard to convince usually *convinces himself* when he gets the full facts about Darling. "Sure it takes a lot to convince me," he admits, "but Darling Valves and Fire Hydrants *have a lot to offer!*"

Ask any Darling user in the water works field what *he* thinks about the design, quality, durability and exacting workmanship for which these two products are noted. Let him relate *his* experiences of easy, dependable operation, reduced maintenance costs, and years of trouble-free service.

Each year more and more Darling Valve and Hydrant installations are sold not on the basis of what *we say—but because of what users say about them!*

DARLING VALVE & MFG. CO.
Williamsport, Pa.
New York Philadelphia Oklahoma City Houston

DARLING
GATE VALVES & FIRE HYDRANTS

The ever-widening usage of Darling Valves proves that performance outweighs promises!

"Never a Failure in Over 22 Years!"

WE like to talk about saving in material and labor—the strong, tight, flexible joints made with Hydro-Tite—the thousands of miles of pipe jointed with it.

More important, perhaps, is the fact that with hundreds of users—each laying pipe under different conditions—not a single one has reported a Hydro-Tite failure.

We make it very easy for you to change over to Hydro-Tite. Our Data Book outlines a novel proposition. Write for it.

EVER TIGHT
HYDRO-TITE

A Symbol of Quality

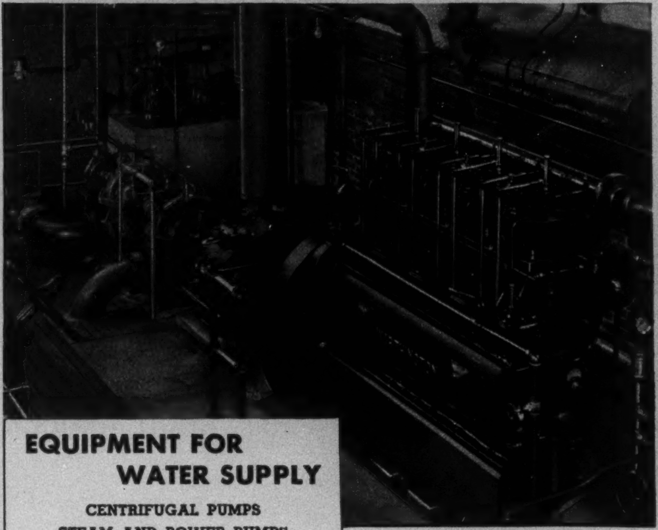
A Dependable Self-Caulking Joint Compound

HYDRO-TITE

HYDRAULIC DEVELOPMENT CORPORATION

Main Sales Office: **50 Church Street, New York, N. Y.**
General Offices and Works: **West Medford Station, Boston, Mass.**

WORTHINGTON



EQUIPMENT FOR WATER SUPPLY

CENTRIFUGAL PUMPS
STEAM AND POWER PUMPS
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SUMP AND DRAINAGE PUMPS
DIESEL ENGINES
GAS ENGINES
STEAM CONDENSERS
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STATIONARY AIR COMPRESSORS
PORTABLE AIR COMPRESSORS
ROCK DRILLING EQUIPMENT
CONSTRUCTION AIR TOOLS
V-BELT DRIVES
AIR LIFT SYSTEMS
*WATER METERS

Worthington 100-horsepower B4 Diesel Engine driving Worthington Two-Stage Centrifugal Pump, through speed-increasing gears, in municipal water works. Worthington Starting Air Compressor in background.

THE above installation is but one of many representative of the wide scope of Worthington Service for Water Supply.

***A complete line of water meters of every type is manufactured by Worthington-Gamon Meter Company, a subsidiary of Worthington Pump and Machinery Corporation.**

● ***Complete descriptive literature available***

WORTHINGTON PUMP AND MACHINERY CORPORATION
WORTHINGTON-GAMON METER COMPANY

General Offices HARRISON, NEW JERSEY *District Offices and Representatives in Principal Cities*

A-36301

ACCURATE to a HAIR is NOT GOOD ENOUGH

Empire Meters must be accurate to a fraction of a hair's breadth

The expression "hairline accuracy" is commonly used to indicate close precision. But hairline accuracy is not close enough for many parts of the Empire Water Meter. Inspections and tests of many Empire parts are made in *ten-thousandths* of an inch. That is the unit of measurement on the gauge shown above, which is used for checking the depth of the web of the Empire piston. This is one of eleven inspections of this one part of this meter.

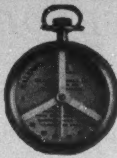
Empire Meters are extremely sensitive and accurate for two reasons. First, correct design. Second, accuracy of construction—maintained by constant inspections. Empire Meter accuracy measured in tenths of thousandths of an inch means accurate measurement of water service—in other words, maximum revenue from metering.

Investigate the Empire balanced-piston water meter. It is a peerless revenue-earner, as proven by thousands of service records over a period of more than a half a century.

NATIONAL METER COMPANY

Executive Offices and Factory: 4209 First Avenue, Brooklyn, N.Y.

BOSTON CHICAGO DALLAS LOS ANGELES SAN FRANCISCO

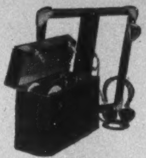


"Boxfindr"

CALDWELL

GOES

AHEAD



"Pipefindr"

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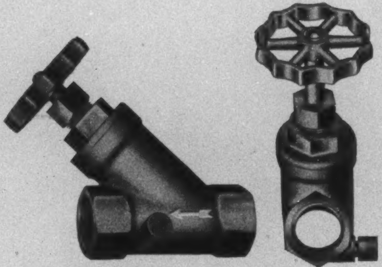

BEST

The ANGLE Compression Stop and Waste Cock with
FULL Sized STRAIGHT Water Way
EASY and POSITIVE in Operation

A-13 Double Copper Tubing Curb Cock

Our NEW Line of BRASS GOODS are built HEAVIER and Carefully Machined, EACH Plug Perfectly GROUND into its INDIVIDUAL body, insuring EASY turning. EVERY Cock is tested at 250 lbs. Hydrostatic pressure and UNCONDITIONALLY GUARANTEED.

A Trial will convince you.

GEORGE A. CALDWELL CO.

BOSTON Mattapan Sq. MASS.

"During the fire our Kennedy SAFETOPS
**operated as easily
as kitchen faucets"**
—wrote the Water Board Chairman

A furious conflagration—the Fire Department working desperately to save adjoining buildings—equipment operated to the limit of capacity. It was the first service test for a number of Kennedy SAFETOP Fire Hydrants which had been installed on the new Water Works System a few months before, and the Department heads gave particular attention to their operation to determine whether they were entirely satisfactory. Later, the Chairman of the Water Board wrote us: "We were highly gratified to find that our selection of Kennedy SAFETOPS was completely justified. During the fire the hydrants opened as easily as kitchen faucets; we found no appreciable pressure drop at the nozzles, and they fulfilled our expectations in every respect."

You need never fear sticking, binding or stiff operation in a Kennedy SAFETOP. The simple, straight-line, central, positive-acting mechanism works easily and quickly, and requires only a few minutes of attention each year to assure maintenance of perfect condition.

The Kennedy Valve Mfg. Co. Elmira, N. Y.

KENNEDY

SAFETOP FIRE HYDRANT
REG. U.S. PAT. OFF.

EDDY

Valves and Hydrants

Distinctive Features of the EDDY Valves

ONLY three parts are moved by the Stem—the ball and the two gates. Each gate is hung from one of the trunnions on the ball. A convex surface at the base of each trunnion fits a concave surface on the back of the gate. This allows the gates to adjust themselves properly to their seats. . . . The gates, being free to revolve on the trunnions, do not always seat in the same position. Gates are center bearing and adjustable. They are forced to their seats with equal pressure at all points. There are two hooks on the ball on sizes 4-inch and larger, which loosely engage with the gates.

Distinctive Features of Our New Swivel Top Hydrants

THIS new hydrant has all the advantages of the popular EDDY fire hydrant, plus several additional features. . . . Nozzles are in a short flanged section of the standpipe, which may be unbolted and turned to different positions. . . . Should the standpipe be broken, only the casting below the swivel head need be replaced. . . . To raise the hydrant to conform to a new grading, simply insert a flanged extension piece below the swivelhead. No digging. To add a steamer nozzle at any time, it is only necessary to replace the swivel head with one having a steamer nozzle.

Besides valves and hydrants to meet the most exacting demands of waterworks service, the complete EDDY Line includes: valves for sewage disposal works; valves for steam, gas and oil; check valves, foot valves, plug valves, shear gates, indicator posts, etc. EDDY valves are made in three classes: Iron Body Bronze Mounted, All Bronze, and All Iron Valves.

Eddy Valve Co.

WATERFORD NEW YORK

LEAD PIPE

Used by leading WATER WORKS for over 50 years. If proper weight is used, combined with good workmanship, your FINAL COST is assured, as REPAIRS are unnecessary. LEAD PIPE is sufficiently ductile to conform to any sagging condition. There is no RUSTING of pipe or joints; no DISCOLORATION of water.

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Every Atom Pure Lead

For calking pipe joints under the most difficult conditions; for overhead joints or in wet places where the use of molten lead is not only impracticable but dangerous — LEAD WOOL may be used to advantage.

It makes an absolutely tight joint which will withstand the highest pressure, yet be sufficiently elastic to allow considerable sagging or settling of the pipe, without danger of leaks.

Compared with the poured joint, in this respect, the superiority of LEAD WOOL is apparent.

LEAD PIPE TIN-LINED LEAD PIPE
PURE BLOCK TIN PIPE SOLDER
DUTCH BOY WHITE LEAD & RED LEAD

Highest Quality Soft Virgin Omaha Pig Lead

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FOR CAST-IRON PIPE
FOR COLD WATER METERS

25c PER COPY

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New England Water Works Association

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POWER: DIESEL, GASOLINE, STEAM, ELECTRIC

PARDEE CHLORINATORS: DIRECT, SOLUTION, VACUUM

PORTABLE: LABOUR SELF-PRIMING PUMP, AIR COMPRESSORS AND TOOLS, *For Rent or Sale*

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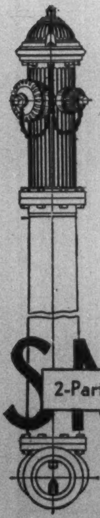


Minimum Trouble and Expense When Breaks Come

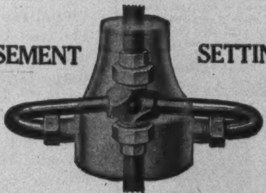
THE Smith Two-Part Standpipe Hydrant was designed to make the expense as small as possible when there is a break as the result, for instance, of careless auto truck driving.

The upper section will always break first. It can easily be renewed. And of course there can be no leakage of water because the main valve is of the compression type.

SMITH
2-Part Standpipe Hydrant

THE A. P. SMITH
MFG. COMPANY
EAST ORANGE, N. J.

The
COPPERHORN
METER COUPLING
for
BASEMENT SETTINGS



- 1 Meter set horizontally at desired height in vertical pipe without ells, nipples or couplings.
- 2 All copper water way. No rusting or corrosion. Freezing will not burst it.
- 3 Smooth oversize tubing and sweeping bends, maximum flow.
- 4 Meter changes do not disturb piping whether the meter in or out.
- 5 On new services it serves as a spacer to connect in the piping.
- 6 Provides a permanent electrical ground connection.

May We Give You Further Information About the Copperhorn?

The FORD METER BOX COMPANY
Wabash, Indiana

HAYS RADIUS SEAL JOINT

This type of joint was designed to meet the specific requirements of certain Water Departments and is available directly on all styles of Hays Copper Service fittings.

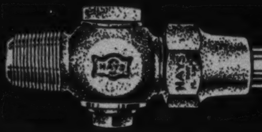
HAYS DOUBLE SEAL JOINT

This joint features a 2-faced pipe flare (45° + 90°) and a 2-faced machined seal (45° + 90°) which is by test the strongest flanged connection available. Available by Adapter on any Corporation Stop and directly on more than 400 styles and sizes of Hays Service and Plumbing fittings.

HAYS begins at the MAIN

Since 1869 Hays has built to the exacting requirements of the Water Works Industry. Tap the Main with a Hays Tapping Machine and follows through with dependable Hays Service Fittings for iron pipe, lead or copper. Hays Corporation Stops and Curb Stops are made in all styles and sizes. Write for Catalog.

USE THE HAYS COPPER SERVICE METHOD



Hays Adapts Copper to meet any Requirements

As a pioneer in the development of copper pipe services, Hays has popularized its use by making it easily adaptable to meet existing line equipment economically. Every community can have the advantage that copper pipe makes possible from Main to Curb to House with the Hays Copper Service Method. Let us have your problem.

HAYS MFG. CO.
ERIE, PA.

HAYS

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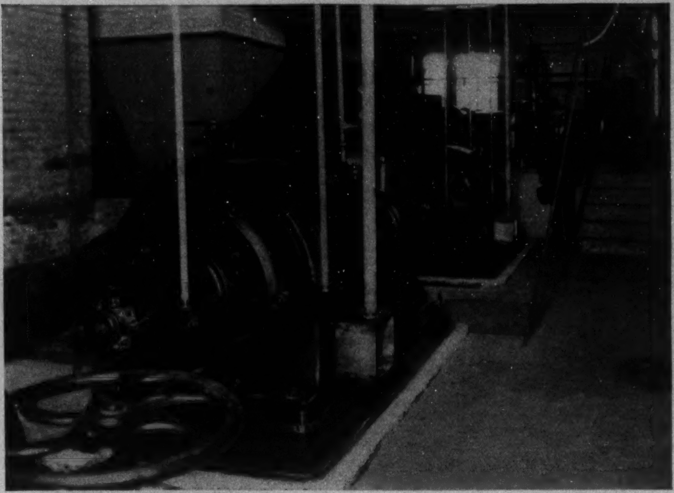
BATH FIXTURES
COPPER PLUMBING
GAS SERVICE GOODS
WATER SERVICE GOODS
IRON PRODUCTS
TAPPING MACHINES



Johnson & Frost, Consulting Engineers

Investigate

"5810"!

Lawrence, Mass., investigated—made a thorough analysis of pump construction—and "5810" won! Emphasis was placed on efficiency, undivided responsibility covering the equipment, and modern engineering design of both pumps and motors.

The above illustration shows the Fairbanks-Morse installation of two 8 in. Figure 5814 pumps driven by two 250 hp. synchronous motors now in operation at the Lawrence Water Works.

An interesting bulletin giving detailed and illustrated description of F-M "5810" will be mailed on request. Write Fairbanks, Morse & Co., 178 Atlantic Ave., Boston, Mass.

FAIRBANKS-MORSE & CO.

POWER • PUMPING • AND • WEIGHING • EQUIPMENT

DE LAVAL

Centrifugal Pumps in Filtration Plant

TOWN OF WEYMOUTH, MASSACHUSETTS.

Water Filtration Plant.—F. O. Stevens, Consulting Engineer.

The three Low Service pumps and two of the High Service pumps are of the single stage type. The High Service pump shown in the left background is a two-stage unit consisting of two single stage pumps connected in series.

This station is another example of De Laval HIGH EFFICIENCY Centrifugal Pumping Units where the annual cost of operation according to accurate field tests will be considerably lower than guaranteed.

All pumping equipment including electric motors, electrical wiring, switchboard and station piping was completely installed by us under one contract.

TURBINE EQUIPMENT COMPANY
OF NEW ENGLAND
80 Federal Street Phone LIB erty 5993-5994 Boston, Mass.

New England Representative for
DE LAVAL STEAM TURBINE COMPANY
TRENTON, N. J.

• • FAMOUS VICTIMS OF WATER BORNE DISEASES

LOST *to the* **WORLD OF LETTERS —HEGEL,** ***Great Rationalist***

HAILED as Aristotle's only rival in the field of logic, Hegel, German Philosopher, fell a victim of cholera—a water borne disease—in 1831. His tenet of philosophy—the application of past experience in solving present problems—would admit no such calamity today. No more need the spectre of water borne disease stalk drinking water supplies—when CHLORINATION'S ready protection offers a constant guard.

W&T Visible Vacuum Chlorinators take the guesswork out of that protection. Years of experience show their complete reliability, low maintenance cost and simplicity of operation.

When the cost of chlorination is so low—less than a penny per person per year—it takes no feat of logic to deduce the fact that every water supply deserves this same protection—a positive safeguard, when W&T Visible Vacuum Chlorinators are used.

The tenet of modern public health practice is "The Only Safe Water is a Sterilized Water."

Technical Publications 38, 157 and 158 describing W&T Visible Vacuum Chlorinators are yours for the asking.

WALLACE & TIERNAN CO., Inc.
Manufacturers of Chlorine and Ammonia Control Apparatus
NEWARK, NEW JERSEY Branches in Principal Cities...Main Factory, Belleville, N. J.
SA-48

. . . and now the World's Best Cone Valves

Cone Valve Is Available for—

ALTITUDE CONTROL
PRESSURE REDUCING
CHECK VALVE
SLUDGE LINES
SEWAGE DISPOSAL
MANUAL CONTROL

GA WORLD'S BEST AUTOMATIC Valves

For more than 30 years Golden-Anderson has been known as the manufacturer of the WORLD'S BEST AUTOMATIC valves.

Now, Golden-Anderson offers you the supreme development in the Thru-Flow or Cone type Valves.

In the new Golden-Anderson Thru-Flow Valve the plug is unseated axially, rotated, and reseated axially, all in one free and frictionless operating movement and drop tight in either open or closed position; this is accomplished by means of a simple and sturdy patented toggle type rotor mechanism which is encased in a bath of oil in the operating head.

The valve itself is just as simple and sturdy, the full flow plug being stronger than pipe of the same area.

And each unit — plug, valve body, operating head, and automatic control — is separate and distinct, designed so that any one unit may be removed from the line without disturbing other units.

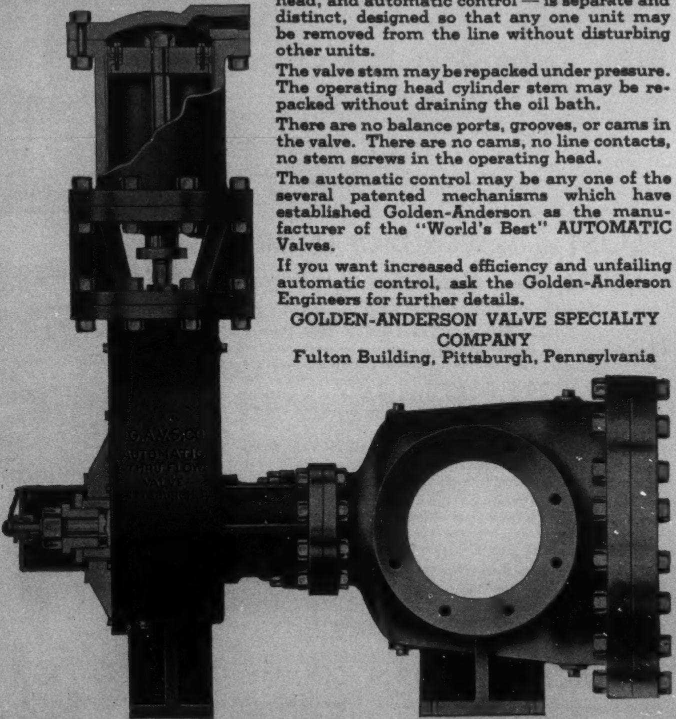
The valve stem may be repacked under pressure. The operating head cylinder stem may be repacked without draining the oil bath.

There are no balance ports, grooves, or cams in the valve. There are no cams, no line contacts, no stem screws in the operating head.

The automatic control may be any one of the several patented mechanisms which have established Golden-Anderson as the manufacturer of the "World's Best" AUTOMATIC Valves.

If you want increased efficiency and unfailing automatic control, ask the Golden-Anderson Engineers for further details.

GOLDEN-ANDERSON VALVE SPECIALTY COMPANY
Fulton Building, Pittsburgh, Pennsylvania



Few Products In Any Field Are So Clearly Recognized for Superiority of Service As

SPUN BITUMASTIC LINING

REG. U.S. PAT. OFF.

The Report of the Committee on PIPE LINE COEFFICIENTS of the New England Water Works Association definitely proves the absolute economic necessity of lining all water pipe.

BITUMASTIC SPUN LINING is assigned a higher value of the coefficient C than any other lining. This insures the highest initial flow. More important —this high flow will be maintained for many years.

BITUMASTIC ENAMEL is not affected by tuberculating waters. Actual inspection of pipe in service and carrying tuberculating waters shows BITUMASTIC unaffected. This is real proof.

No taste, color, or odor imparted to the water.

Wailes Dove-Hermiston Corporation

General Office
17 Battery Place
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W. D. Barker, Room 606
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The "COREY" Hydrant

Why you should use GENUINE COREY HYDRANTS

Water to Nozzles quicker than other Hydrants.

Standpipe can be removed and replaced without shutting off water in main.

Ease of operation insured by knuckle joint principle.

Only 13 turns to completely open or completely close, but full flow with only 4 turns.

Nozzles screwed in — not leaded.

Can be lengthened without shutting off water.

Will not flood if broken.

Positive Drip — cannot freeze.

Standpipe can be revolved quarter turns — Nozzles always in right direction.

Ask for our Catalog "G"

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New England Sales Manager, Lock Box 2, Northboro, Mass.

RENSSELAER VALVE COMPANY
TROY, N. Y.

DONALDSON IRON CO.

MANUFACTURERS
...OF...

CAST
IRON
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CAST IRON GAS & WATER PIPE

...AND...

Special Castings for Water and Gas.
Also Flange Pipe and Fittings.

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METER RATE SHEETS

For plotting average rates paid per annum by water consumers

Single sheet	$0.05
100 sheets, for thousands of gallons per annum	2.25
100 sheets, for hundreds of cubic feet per annum	2.50

New England Water Works Association

15 HOURS OF POWER HAMMER POUNDING 90,000 separate impacts—100 a minute

● Even under this terrific and sustained punishment MINERALEAD Jointing held tight—didn't leak a drop. ● Write for particulars of this interesting test—important to everyone who lays Bell and Spigot Pipe.

The ATLAS MINERAL PRODUCTS COMPANY *of Penna.* Mertztown, Pa.

MINERALEAD

For JOINTING BELL
and SPIGOT MAINS

Stops and Fittings

**Tested under 250 lbs. water pressure . . .
Ground and lapped . . . Highest grade bronze . . .
For absolute reliability specify UNION**

UNION WATER METER COMPANY
Established 1860
WORCESTER, MASS.

WATER METERS
CHRONOMETER VALVES

STOPS AND FITTINGS
PRESSURE REGULATORS

CEMENT LINED SERVICE PIPE

Cement lined pipe has eliminated corrosion and metal contamination for 60 years.

Write for Literature

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LYNN, MASS.

PIERCE-PERRY CO.

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Youngstown Steel Pipe.
Valve and Service Boxes.

236 Congress St., Boston, Mass.
Telephone, Hancock 7817-7818.

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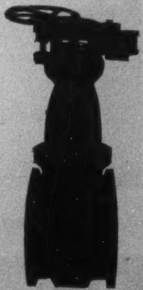
This Motor-Operated Valve

The efficiency of Ludlow motor-operated valves has been proved by test and demonstration for over 10 years. Available in numerous types and sizes with single or multi-station remote control. They save time, afford protection, assure positive performance. One of many Ludlow specialties which embody highest engineering design and construction.

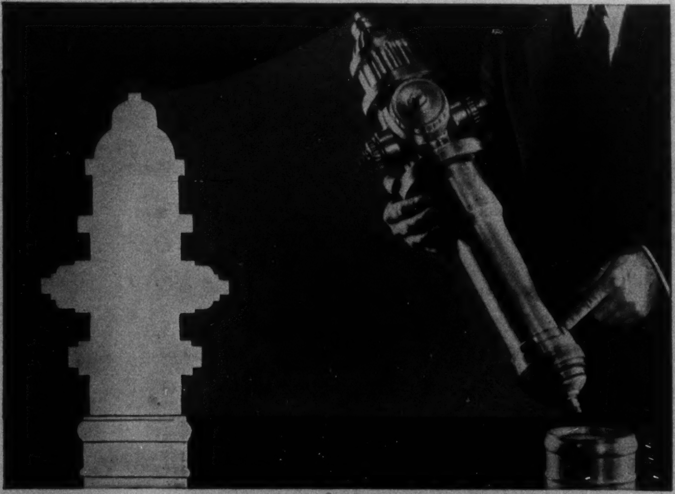
The LUDLOW VALVE MFG. CO.
TROY, N. Y.



IN *15 Minutes* YOU CAN *Renew*

MATHEWS HYDRANTS

This barrel contains all working parts. It is interchangeable with every Mathews Hydrant ever made of the same diameter and trench depth. It is inserted without digging a spoonful of earth or breaking an inch of pavement. Whether Mathews Hydrants are 60 years old and in need of modernizing or 6 months old and broken by traffic, you can renew them in 15 minutes and save excessive installation costs.



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R. D. WOOD CO. 400 CHESTNUT STREET
PHILADELPHIA EST. 1803

Makers of **SAND-SPUN PIPE,** the lighter, stronger pipe, centrifugally cast in sand molds

CLASSIFIED DIRECTORY OF ADVERTISEMENTS.

	Page
AIR COMPRESSORS.	
Field, Walter W. & Son	iii
Hayes Pump and Machinery Co.	viii
ASBESTOS CEMENT PIPE.	
Johns-Manville	xxxvi
BRASS GOODS.	
(See also Pipe, Brass.)	
Caldwell, George A., Co.	xv
Cement Lined Pipe Co.	xxvii
Hays Mfg. Co.	xx
Kitson Co.	xxxvi
Pierce-Perry Co.	xxvii
Red Hed Mfg. Co.	xxxiv
Smith Mfg. Co., The A. P.	xix
Union Water Meter Co.	xxvii
CALKING MACHINERY AND TOOLS.	
Smith Mfg. Co., The A. P.	xix
CAST IRON PIPE. (See Pipe, Cast Iron.)	
CEMENT LINED PIPE. (See Pipe, Cement Lined.)	
CHECK VALVES.	
Columbian Iron Works	xxxiii
Darling Valve & Mfg. Co.	xxxii
CHEMICAL FEED APPARATUS.	
Builders Iron Foundry	ix
Wallace and Tiernan Co., Inc.	xxiii
CHLORINATORS.	
Builders Iron Foundry	ix
Wallace & Tiernan Co., Inc.	xxiii
CLEANING WATER MAINS.	
National Water Main Cleaning Co.	viii
COCKS, CURB AND CORPORATION.	
Caldwell, George A., Co.	xv
Hays Mfg. Co.	xx
Kitson Co.	xxxvi
Pierce-Perry Co.	xxvii
Red Hed Mfg. Co.	xxxiv
Smith Mfg. Co., The A. P.	xix
Union Water Meter Co.	xxvii
CONCRETE PIPE. (See Pipe, Concrete.)	
CONDENSERS.	
Hayes Pump and Machinery Co	viii
CONSTRUCTION EQUIPMENT.	
Edson Corp., The	x
CONTRACTORS.	
Ferullo, G., Inc.	iii
Hughes, Edward F.	iii
Layne-Bowler New England Co.	iii
National Water Main Cleaning Co.	viii
Ross, Anthony & Son	iii
CONTRACTORS' EQUIPMENT.	
Field, Walter W. & Son, Inc.	iii
COUPLINGS, REPAIR	
Caldwell, George A. Co.	xv
CURB BOXES.	
Bingham and Taylor	iv
Caldwell, George A., & Co.	xv
Hays Mfg. Co.	xx
CURB AND VALVE BOX FINDERS.	
Caldwell, George A., Co.	xv
DIAPHRAGMS, PUMP.	
Edson Corp., The	x
ENGINEERS.	
Barbour, Frank A.	ii
Barrows, H. K.	ii
Ellsworth, Samuel M.	ii

CLASSIFIED DIRECTORY OF ADVERTISEMENTS *(Continued).*

	PAGE
ENGINEERS – *Continued*	
Fay, Spofford & Thorndike	ii
Fuller & Everett	ii
Goodnough, Inc., X. Henry	ii
Metcalf & Eddy	ii
Pirnie, Malcolm	ii
Pitometer Co.	ii
Thorpe, Lewis D.	ii
Weston & Sampson	iii
Whitman & Howard	iii
ENGINES. (See Pumps and Pumping Engines.)	
EQUIPMENT. (See Contractors' Equipment.)	
ERECTORS, WATER WORKS AND POWER MACHINERY.	
Hayes Pump and Machinery Co.	viii
Turbine Equipment Co.	xxii
FEED WATER HEATERS.	
Hayes Pump and Machinery Co.	viii
Ross Valve Mfg. Co.	viii
FILTER RATE CONTROLLERS AND GAGES. (See Rate Controllers.)	
FILTERS AND WATER SOFTENING PLANTS.	
Ross Valve Mfg. Co.	viii
FILTRATION PLANT EQUIPMENT.	
Builders Iron Foundry	ix
Ross Valve Mfg. Co.	viii
Wallace & Tiernan Co., Inc.	xxiii
FLEXIBLE JOINTS.	
U. S. Pipe and Foundry Co.	Facing back cover
FLAP VALVES.	
Columbian Iron Works	xxxiii
FURNACES, ETC.	
Atlas Mineral Products Co.	xxvi
Leadite Co., The	Back cover
Smith Mfg. Co., The A. P.	xix
GAGES, SURFACE, RESERVOIR AND SPECIAL WATER WORKS.	
Builders Iron Foundry	ix
GATE VALVES. (See Valves.)	
HOSE, SUCTION AND CONDUCTION.	
Edson Corp., The	x
HOTELS.	
Pennsylvania	Following front cover
HYDRANT PROTECTORS.	
Edson Corp., The	x
HYDRANTS, FIRE.	
Columbian Iron Works	xxxiii
Darling Valve & Mfg. Co.	xxxii
Eddy Valve Co.	xvii
Kennedy Valve Mfg. Co. "Newtype"	xvi
Ludlow Valve Mfg. Co.	xxvii
Rensselaer Valve Co. "Corey"	xxv
Ross Valve Mfg. Co.	viii
Smith Mfg. Co., The A. P.	xix
Wood, R. D., & Co.	xxviii
INSTRUMENTS. (See Water Works Instruments.)	
LEAD.	
National-Boston Lead Co.	xviii
LEAD PIPE. (See Pipe, Lead.)	
LEAD WOOL.	
National-Boston Lead Co.	xviii
LEAK FINDERS.	
Pitometer Co.	ii
METER RATE SHEETS.	
New England Water Works Association	xxvi

CLASSIFIED DIRECTORY OF ADVERTISEMENTS (*Continued*).

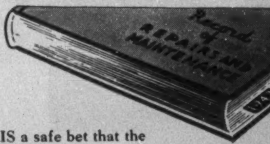
	PAGE
METERS, WATER AND OIL.	
Builders Iron Foundry	ix
Gamon Meter Co.	xiii
Hersey Mfg. Co.	v
National Meter Co	xiv
Neptune Meter Co.	vi
Pitometer Co.	iii
Pittsburgh Equitable Meter Co.	vi
Union Water Meter Co.	xxvii
Worthington-Gamon Meter Co.	xiii
METER COUPLINGS.	
Ford Meter Box Co.	xix
Kitson Co.	xxxvi
METERS (VENTURI TYPE).	
Builders Iron Foundry	ix
Columbian Iron Works	xxxiii
National Meter Co.	xiv
METER BOXES.	
Bingham and Taylor	v
Ford Meter Box Co.	xix
METER TESTERS.	
Ford Meter Box Co.	xix
OIL ENGINES, DIESEL.	
Fairbanks-Morse & Co.	xxi
Hayes Pump and Machinery Co.	viii
PIPE, BRASS.	
Caldwell, George A. Co.	xv
Pierce-Perry Co.	xxvii
PIPE, CAST IRON (AND FITTINGS).	
Builders Iron Foundry	ix
Donaldson Iron Co.	xxvi
U. S. Cast Iron Pipe and Foundry Co.	Facing back cover
Warren Foundry and Pipe Corp.	x
Wood, R. D., & Co.	xxviii
PIPE, CEMENT LINED.	
Cement Lined Pipe Co.	xxvii
Union Water Meter Co.	xi
PIPE, CONCRETE.	
Lock Joint Pipe Co.	Facing front cover
PIPE CUTTING MACHINES.	
Smith Mfg. Co., The A. P.	xix
PIPE JOINTING MATERIAL.	
Atlas Mineral Products Co.	xxvi
Hydraulic Development Co.	xii
Leadite Co., The	Back cover
PIPE, LEAD.	
National-Boston Lead Co.	xviii
PIPE LINING.	
Wailes Dove-Hermiston	xxv
PIPE, WROUGHT IRON AND STEEL.	
Pierce-Perry Co.	xxvii
PLUG VALVES.	
Columbian Iron Works	xxxiii
PITOMETERS.	
Pitometer Co.	ii
PORTABLE AIR COMPRESSORS. (See Air Compressors.)	
PRESSURE REGULATORS.	
Caldwell, George A., Co.	xv
Golden-Anderson Valve Specialty Co.	xxiv
Ross Valve Mfg. Co.	viii
Union Water Meter Co.	xxvii

CLASSIFIED DIRECTORY OF ADVERTISEMENTS *(Continued).*

	PAGE
PROVERS, WATER.	
Pittsburgh Equitable Meter Co.	vii
PUMPS AND PUMPING ENGINES.	
Edson Corp., The	x
Fairbanks-Morse & Co.	xxi
Hayes Pump and Machinery Co.	xix
Ross Valve Mfg. Co	viii
Turbine Equipment Co.	xxii
Wood, R. D., & Co.	xxviii
RATE CONTROLLERS.	
Builders Iron Foundry	ix
SHEAR GATES.	
Columbian Iron Works	xxxiii
SLEEVES AND VALVES, TAPPING.	
Columbian Iron Works	xxxiii
Ludow Valve Mfg. Co.	xxvii
Rensselaer Valve Co.	xxv
Smith Mfg. Co., The A. P.	xix
SPECIFICATIONS, Cast Iron Pipe and Cold Water Meter.	
New England Water Works Association	xxvi
SLUICE GATES.	
Columbian Iron Works	xxxiii
SUPPLIES AND TOOLS.	
Caldwell, George A., Co.	xv
Field, Walter W. & Son, Inc.	iii
Hays Mfg. Co.	xx
Leadite Co., The	Back cover
Pierce-Perry Co.	xxvii
Smith Mfg. Co., The A. P.	xix
TAPPING MACHINES.	
Columbian Iron Works	xxxiii
Hays Mfg. Co.	xx
Red Hed Mfg. Co.	xxxiv
Smith Mfg. Co., The A. P.	xix
TAPPING SLEEVES. (See Sleeves and Valves, Tapping.)	
VALVE BOXES.	
Bingham and Taylor	v
Caldwell, George A. Co.	xv
Columbian Iron Works	xxxiii
Ford Meter Box Co.	xix
Rensselaer Valve Co.	xxv
Wood, R. D., & Co.	xxviii
VALVE INSERTING MACHINES.	
Smith Mfg. Co., The A. P.	xix
VALVE SPECIALTIES.	
Golden-Anderson Valve Specialty Co.	xxiv
Kitson Co.	xxxvi
VALVES, GATE.	
Darling Valve & Mfg. Co.	xxxii
Eddy Valve Co.	xvii
Jenkins Bros.	xxxv
Kennedy Valve Mfg. Co.	xvi
Ludlow Valve Mfg. Co.	xxvii
Rensselaer Valve Co.	xxv
Ross Valve Mfg. Co.	viii
Smith Mfg. Co., The A. P.	xix
Wood, R. D., & Co.	xxviii
VALVES, REGULATING.	
Golden-Anderson Valve Specialty Co.	xxiv
Ross Valve Mfg. Co.	viii
Union Water Meter Co.	xxvii
WATER WASTE DETECTION.	
Pitometer Co.	ii
WROUGHT IRON PIPE. (See Pipe, Wrought Iron and Steel.)	
WATER WORKS INSTRUMENTS.	
Caldwell, George A. Co.	xv
WATER WORKS JOURNALS.	
Journal of the New England Water Works Association	viii
WELL CONNECTIONS.	
Red Hed Mfg. Co.	xxxiv

Figure it out

ACROSS THE YEARS!


Record of REPAIRS AND MAINTENANCE
1942
1941
1940
1939

IT IS a safe bet that the same things will happen to your fire hydrants in the next five years that happened during the last five years. This means that in a city of any size there will be a number of smashed hydrants — a number of main valves to replace—a number of hydrants to be lengthened—a number of other changes and repairs to be made.

If the hydrants smashed by trucks or automobiles are Columbians, (with the safety flange and coupling) the cost of repairing breakage will be about five dollars. But if they are hydrants that lack this feature, it will be about $50.00! To remove the main valve of the Columbian with its bronze shoe bushing will be a simple job. To remove a main valve when the seat ring is "frozen" into an iron thread in the shoe, is a tough job usually involving a lot of digging and lifting. If the grade level changes the Columbian can be lengthened to conform to any new grade in less than 20 minutes, but usually the lengthening of a hydrant is a job that calls for a lot of digging and lifting—often, water cut-off.

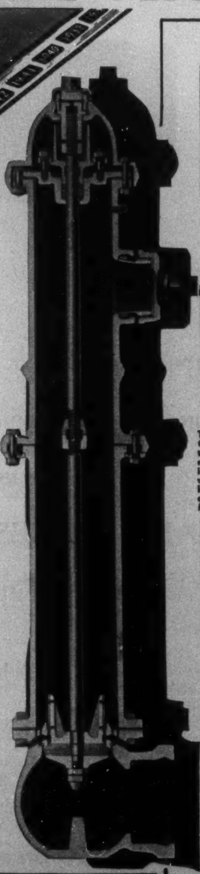
Figure the excessive cost of these repairs and the time and money wasted in making them. Figure the excessive cost of replacing ordinary oak tanned leather main valves which offer half the service life of the special chrome tanned leather used in Columbians. Figure the cost of endless oiling—totally eliminated in the self-oiling Columbian. Figure the cost of breakage from freezing—eliminated in the non-freezing Columbian. You will then know why so many cities are now installing only Columbians.

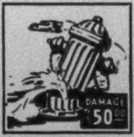
COLUMBIAN IRON WORKS
Chattanooga, Tenn.

Division of MUELLER CO.,
Decatur, Ill.

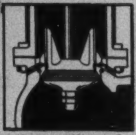
COLUMBIAN

FIRE HYDRANTS AND GATE VALVES

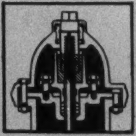




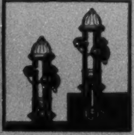
$ 5.00 — or $ 50.00?
A hydrant is smashed by a truck or automobile. Usual repaircost about $50.00. The Columbian Safety Flange and coupling confines the damage to a few simple parts costing about $5.00.



Hours or Minutes?
This bronze bushing in the Columbian shoe makes it easy to remove the seat ring and main valve. When the seat ring is frozen into iron threads water must be cut off and the hydrant dug up. No water cut-off or digging with Columbian. Minutes instead of hours.



Constant Oiling—or Self-Oiling?
The perpetual, self-oiling feature of the Columbian eliminates the troublesome chore of oiling. Oiling is often forgotten. The self-oiling feature never forgets.



Time Wasted or Time Saved?
Grades change. Hydrants must be lengthened. This usually requires water cut-off and digging. But not with Columbians. Note how easy it is to add extension section.

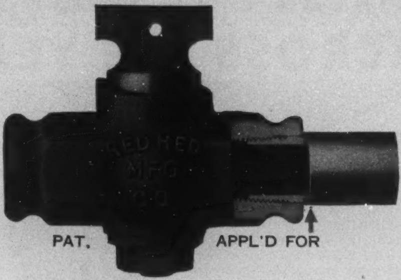


Fig. 220

TEE HEAD RECESSED STOP AND WASTE

Iron or brass service pipe threads
fully protected from corrosion and breakage
by the use of
RED HED RECESSED Curb Stops
and Fittings

Made by

RED HED MFG. CO.

368 CONGRESS ST., BOSTON, MASS.

Makers of RED HED Brass goods for Water Works

RESERVE STRENGTH

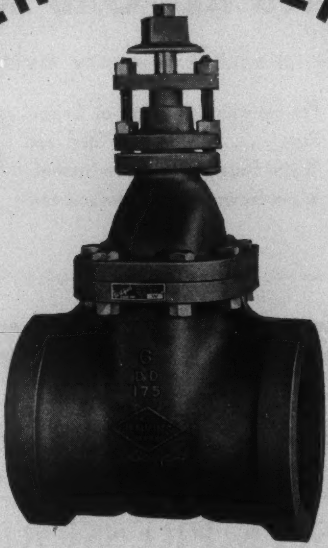
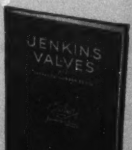


Fig. 883
Double Disc
Parallel Seat

—makes ordinary duty easy for a Jenkins

STRENGTH is emphasized in making Jenkins Iron Body Gate Valves for water works service. In both the Solid Wedge and the Double Disc Parallel Seat valves are many superior features that build up strength . . . that make a "Jenkins" capable of handling ordinary duty with ease. The result is longer valve life and less maintenance. This great reserve strength also enables a "Jenkins" to carry-on even if extraordinary strains are encountered.

When you need Iron Body Gates make your selection from the Jenkins Catalog. A special 32 page section gives you comprehensive data on Iron Body Gates in sizes from 2 inches to 48 inches; Cast Steel Gates; Electrically and Hydraulically Operated Gates; Indicator Posts; Floor Stands and Gearing arrangements. Use this Book to save time and safeguard your valve investment.



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Jenkins Valves

BRONZE—IRON—STEEL SINCE 1864

K-CO

Inverted Key Curb Stops

— available in every style

For use with Lead, Iron or Copper Pipe . . . in Stop and Stop and Waste Patterns. Each one "tested" at our factory for leakage and ease of operation.

C167—CURB STOP
Inverted key—roundway
For iron pipe

C168—CURB S. & W.
Inverted key—roundway
For iron pipe

We also make Corporation Stops, Meter Couplings and other Brass Water Service Items.

KITSON COMPANY
2409-15 Westmoreland St. Philadelphia, Pa.

Kitson Safety Devices (Lovekin Patents) for Domestic Water Heaters	Quality Brass Goods for Gas, Water and All Plumbing Uses

ESTABLISHED 1897

TRANSITE PRESSURE PIPE

An Asbestos Product for
economical water transportation

Ends tuberculation . . . Soil corrosion . . . Electrolysis

Costs less to install . . . Minimizes operating and maintenance costs

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The Journal of the New England Water Works Association

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Tested and used for over 35 years.
Saves at least 75%

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Girard Trust Company Bldg. Philadelphia, Pa.

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LEADITE
REG. U.S. PAT. OFF.
CEMENT
FOR JOINTING WATER MAINS
MANUFACTURED BY
THE LEADITE COMPANY
PHILADELPHIA, PA.

No Caulking